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A SAFETY ANALYSIS OF THE OAK RIDGE CRITICAL EXPERIMENTS FACILITY

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A SAFETY ANALYSIS

of the

OAK RIDGE CRITICAL EXPERIMENTS FACILITY

Prepared by

The Facility Staff

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
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19

CONTENTS

LIST OF FIGURES

FOREWORD

A Safety Review of the Oak Ridge Critical Experiments Facility was first prepared in February 1962. After perusal by the Laboratory's Reactor Operations Review Committee, it was revised in April. Suggestions by the Safety Review Committee of the Oak Ridge Operations Office of the U. S. Atomic Energy Commission were incorporated in August 1962. This document was extensively revised and a draft reissued during August 1966. Comments subsequently received from the Oak Ridge Operations Office and from the Laboratory's Criticality Committee were considered and incorporated where appropriate. Revision 1 of the document was issued in February 1967.

A SAFETY ANALYSIS
of the
OAK RIDGE CRITICAL EXPERIMENTS FACILITY

ABSTRACT

This memorandum describes the Critical Experiments Facility, located in the Y-12 Area of Oak Ridge, with particular reference to the safety features of both the laboratory itself and the procedures established for the experiments constituting the specialized use for which the laboratory was constructed. A pertinent factor in evaluating the safety features is the absence of a significant inventory of fission products in experimental materials.

It is concluded from past experiences in this and other laboratories and from theoretical analyses of the cause and progress of such events that an accidental criticality excursion yielding the order of 10^{18} fissions has a small but finite probability of occurrence. Protection against radiation from such an event, conforming to the requirements of US AEC Manual Chapter 0524, is provided in designated areas by experimentally proven shielding. A plan adequate to cope with all expected emergencies, including any requiring evacuation of the immediate vicinity, is in effect. The location of the Facility with respect to areas accessible to the public and the conservative assumptions of the air transport of fission products and other contaminants provide confidence in personnel protection according to the criteria of Federal Regulation 10 CFR 100 except for unclad plutonium. For this case the limits are marginal and require more careful evaluation at such time as plutonium may be studied.

It is further concluded that the greatest potential danger to personnel is in the course of preparing fissile materials for experiments, in their storage and transport, and from contamination by radioactive materials, plutonium and polonium for example, dispersed from faulty neutron sources or radiation detectors.

As in many like instances, ultimate reliance for safety must be placed on the knowledge and caution of the individual staff members.

INTRODUCTION

The Oak Ridge Critical Experiments Facility was constructed expressly for experiments with nuclear chain-reacting assemblies in which there is an insignificant buildup to fission products. The programs have required the accumulation of basic reactor physics data, the determination of the critical dimensions of material assemblies, and the study of nuclear reactor designs.

Only in exceptional instances is it necessary to operate critical experiments at nuclear powers sufficiently high to present radiation hazards to the individuals performing the experiments, even though the manipulation be manual as it was, indeed, in early practices. However, the ever present probability of personnel or equipment failure, which could lead to high-level radiation emission by a supercritical array, requires a laboratory which is equipped for remote performance of these experiments.

A laboratory in which critical experiments are performed must also be capable of accommodating a very wide variety of activities in contrast to a reactor installation which may remain fixed in construction and operation over an extended period. The experimental equipment used for these purposes must be adaptable to many configurations of materials of interest dictated by the demands of the programs. Since the time required for the performance of a particular experiment may be only a few hours, it is not economically feasible to pattern instrumentation and controls after those conventionally prepared for long-range reactor operation. For this reason, and, more importantly, because the very purpose of these exploratory experiments may truly be the evaluation of those factors upon which reactor safety will subsequently be designed, critical experiments are somewhat more vulnerable to nuclear accidents than are operating reactors. On the other hand, the overall consequences of a nuclear accident with a critical assembly are very much less severe than are those associated with reactors, primarily because of the absence of a significant inventory of fission products built up in the fissile material. In fact, it is highly desirable to avoid such a fission-product buildup in order to allow manual adjustments of the experimental equipment and materials.

Many safety features for the successful operation of critical experiments must, therefore, be permanently built into the laboratory itself rather than be incorporated into each experimental setup. Necessary radiation shielding, for example, is a part of the laboratory structure. Special consideration must be given to the design of ventilation systems to minimize dispersal of radioactive contamination. Since the purpose of most critical experiments is to determine the characteristics of fissile materials in new configurations, it is impossible to predict the absolute rates of changes of reactivity in advance of the experiment itself. Each experimental assembly must therefore embody control and safety devices peculiar to the type of experiment under study and to the properties of the materials used.

Prior to the construction of the laboratory to be described here, several critical experimental programs had been carried out at the Oak Ridge National Laboratory and at the Oak Ridge Gaseous Diffusion Plant. The inadequacy of the facilities at these two locations was recognized in 1949 in light of the expected demands for further experimentation in both the investigation of the safety of metallurgical and chemical processes and the support of reactor designs. This latter need was further emphasized by a then-active program in Oak Ridge on the development of nuclear propulsion for aircraft. At that time it was decided that a laboratory adequate for this variety and quantity of experimentation would be established, that the various programs of critical experiments in Oak Ridge would be combined, and that the work would be administered under the Oak Ridge National Laboratory. The new laboratory was occupied on September 1, 1950 and has since been the scene of an extremely wide variety of critical and near-critical experiments with fissile uranium isotopes.

It is the purpose of this memorandum to describe the laboratory, designated locally as Building 9213, Y-12 Area, and officially as the Oak Ridge Critical Experiments Facility, to discuss the types of experiments performed, and to describe the equipment and procedures representative of more than 16 years of experience in this Facility. Particular emphasis is placed upon the safety of these operations.

It is important to summarize, with statistics, the operating experience at the Facility. Since its occupancy in 1950 through calendar year 1966 more than 16,500 start-up operations, representing nearly that many different configurations, have been accomplished. Perhaps as many as 95% of the assemblies were made critical. Most of the experiments were at or near critical for no more than 20 minutes. Of these operations, 158 were terminated by emergency shutdown procedures and of these 158, three, or 0.02% of all startups, were terminated by the effects of unplanned high radiation fields. The majority of the other emergency actions occurred because of power or instrument failures; 61 occurred by intent, either to test equipment response or as a planned experiment.

Adherence to the fundamental operational practices outlined in this memorandum, supported by careful reviews by internal Laboratory committees, is expected to promote continued safe and efficient operation of the Oak Ridge Critical Experiments Facility. Ever-present vigilance and concern for personnel protection by the experimenters in the Facility must be the final safeguard in this endeavor.

I. PHILOSOPHY

The operations within the Facility are guided by a few fundamental practices, conditions, and beliefs which are summarized here. More detailed discussions of some of them appear in later sections of this memorandum.

1. Protection of personnel, both employee and public, from radiation and other accidental injury is of the utmost importance.
2. Next in order of importance is prevention of unnecessary damage to property, followed closely by the consummation of a sound technical program.
3. There can be no protection against the ultimate in intentionally perpetrated accidents or other acts of sabotage.
4. Whereas every reasonable effort is made to avoid unscheduled criticality, no absolute guarantee thereof can be made. There is, however, always assurance of operable mechanisms for termination of criticality within a short time following its occurrence.

5. The cardinal design criterion for the usual delayed-critical experiment is provision whereby reactivity can be automatically removed at a rate greater than that at which it can be added by normal means. The absolute values of rates of reactivity change, whether positive or negative, are unimportant provided this criterion is met. This criterion does not apply to pulse-type devices, and possibly other experiments, because dependence can be placed on intrinsic shutdown mechanisms, such as a negative temperature coefficient of reactivity.
6. Experiments are carried on by experienced personnel with well designed and regularly tested equipment. Establishing the integrity of the mechanical equipment is of utmost importance in the consideration of every experiment.
7. The staff of the Facility is sufficiently expert in the several disciplines -- electrical, electronic, mechanical, nuclear -- to constitute a closely integrated team continuously knowledgeable in the day-to-day functions, accomplishments, and needs of the Facility. With such an organization there is no compromise of safety by poor communication between operating and service groups.
8. A carefully planned and rehearsed emergency procedure is in effect. Orderly action and full communication are recognized as essential in any emergency. On the other hand, the local procedures grant blanket permission to staff members directly informed of the emergency to deviate from the written procedures if to do so is, in their judgement, a better action.
9. Recognition of the inevitable accident potential was cause for the design and construction of a relatively costly laboratory having unique features providing the protection demanded in Item 1. Many of the protection capabilities attributable to construction and to location have been directly measured and found more than adequate. All other capabilities have been analyzed by experts in respective topics and also found acceptable

for the conditions expected. These characteristics of the Facility are best expressed by the Atomic Energy Commission[1] in describing the Facility as "... a critical experiment laboratory specifically designed to accommodate such occurrences [an unplanned criticality incident], since events of this nature cannot be considered entirely unexpected in an experimental facility of this sort."

II. OPERATING SAFETY LIMITS

The following safety limits have been established by the Oak Ridge National Laboratory for application to operations at the Critical Experiments Facility. Part I is, essentially, a "Code of Good Practices for the Performance of Critical Experiments," prepared by the Standards Committee of the American Nuclear Society. Part II is a supplement containing additional limits uniquely applicable to the Critical Experiments Facility. All operations within the Facility will be conducted within the limits herein stated. Changes to these safety limits must be approved by the ORNL Criticality Committee and by the Oak Ridge Operations Office of the AEC before becoming effective.

Part I. General Operating Limits

1. DEFINITIONS

1.1 Limitations

The definitions given below should not be regarded as encyclopedic. Other terms, whose definitions are accepted by usage and by standardization in the nuclear field, are not included.

1.2 Glossary of Terms

1.2.1 Shall, Should, and May. The word "shall" is used to denote a requirement, the word "should" to denote a recommendation, and the word "may" to denote permission,

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1. Operational Accidents and Radiation Exposure Experience, TID-22268, p. 27, U. S. AEC (1965).

neither a requirement nor a recommendation. In order to conform with this standard all operations shall be performed in accordance [redacted], but [redacted]

1.2.2 Critical Experiments (Experiment). An experiment or series of experiments performed with fissionable material which may be at or near the critical state.

1.2.3 Critical Assembly (Assembly). A device or physical system, containing fissionable material, with which critical experiments are performed.

1.2.4 Nuclear Excursion. The liberation of an undesirable quantity of energy as the result of a criticality accident.

1.2.5 Assembly Area. A region in the vicinity of a critical assembly where there would be inadequate personnel protection in the event of a nuclear excursion.

1.2.6 Neutron Source. Any material, combination of materials, or device emitting neutrons, including materials undergoing fission.

1.2.7 Safety Device. A mechanism designed to reduce the reactivity of a critical assembly.

1.2.8 Scram. A rapid reduction of reactivity to subcriticality.

2. ADMINISTRATIVE PRACTICES

2.1 Responsibility for the safety of a critical experiment shall be assigned unambiguously by management.

2.2 Each new experimental program shall be reviewed in a manner approved by management with particular emphasis on safety features.

2.3 Before an experiment begins, an experiment plan shall be reviewed by all who are expected to take part in the experiment.

2.4 At least two persons shall be present while a critical experiment is being performed.

2.5 Manual operations with fissionable material, such as storage, transfer, and non-remote addition of reactivity to an assembly, shall be in accordance with American Safety Standard for Operations with Fissionable Materials Outside Reactors, ASA N6.1-1964.

2.6 Additions of reactivity beyond those permitted by Paragraph 2.5 shall be made by remote operation. Such additions of reactivity shall be reversible and continuously adjustable except when the resulting assembly will be subcritical or supercritical by a known amount.

2.7 No person shall enter an assembly area during the performance of a critical experiment without the approval of the person responsible for safety. During an addition of reactivity that requires remote operation, personnel shall be protected from unacceptable consequences of a nuclear excursion.

2.8 If anyone participating in the operation of an experiment expresses doubt of the safety of a particular action or step, the experiment shall be suspended until the doubt is resolved.

2.9 A record of the status and operation of the assembly, with particular reference to its safety features, shall be maintained.

2.10 An emergency plan approved by management shall be in effect.

2.11 Adequate personnel radiation monitoring shall be provided.

3. EQUIPMENT CRITERIA

3.1 There shall be safeguards against operation of critical assembly equipment by unauthorized personnel.

3.2 Communication shall exist between personnel at the control console and those who may be at the critical assembly.

3.3 A signal audible to personnel within the assembly area shall provide an indication of the neutron level during adjustments affecting reactivity.

3.4 A source of neutrons sufficient to produce a meaningful indication of multiplication shall be present during any approach to criticality, except special experiments in which reactivity effects are known may be performed without a source present.

3.5 Each assembly shall be provided with a safety device that is actuated automatically at a preset radiation level and can be actuated manually. This safety device shall be capable of removing reactivity more rapidly than it can be added by any normal operation.

3.6 At least two radiation monitors shall be capable of independently initiating a scram of the assembly at a preset radiation level.

3.7 Loss of actuating power to any safety device shall produce a scram.

3.8 A scram signal shall prevent further significant increase of reactivity.

3.9 During critical experiments there shall be at least two instruments providing indication of the neutron level within the assembly. These may be the same as those required by paragraph 3.6.

3.10 The status of any variable for fine control of reactivity shall be continuously displayed at the control console. The limiting conditions or positions of safety devices shall also be displayed.

4. <u>OPERATIONAL PRACTICES</u>

4.1 The satisfactory performance of newly installed or significantly altered control equipment or safety devices shall be established before achieving initial criticality.

4.2 The proper functioning of the required number of safety devices shall be established prior to starting operations each day that an experiment is to be initiated. In the course of these tests or early in each day's operation, the response of each required detector system to a change in neutron or gamma-ray level shall be noted.

4.3 Additions of reactivity requiring remote operation shall be guided by neutron detector response. During an initial approach to criticality, a reactivity addition shall not be made unless the effects of any preceding additions have been observed and understood.

4.4 Any unexpected behavior of the assembly or its associated equipment should be evaluated promptly.

4.5 Additions of reactivity requiring remote operation shall not be made simultaneously by two or more persons, unless the effect of such additions has been measured.

4.6 Additions of reactivity requiring remote operation shall not be made simultaneously by two or more distinct methods (e.g., by rod motion and by water addition), unless the effect of such additions has been measured.

Part II. Limits Specifically Applicable to the Oak Ridge Facility

1. DEFINITIONS

1.1 A Senior Experimenter is a person having a working knowledge of reactor theory and at least one year of operational experience at this Facility and who preferably, but not necessarily, has past experience with experiments in which the form of the fissile material was similar to that of a proposed experiment.

1.2 An Experimenter is a person with the qualifications of a Senior Experimenter except he is not required to be versed in reactor theory. The duties of an Experimenter may be performed by a Senior Experimenter.

1.3 Exclusion Areas are portions of the Critical Experiments Facility having insufficient shielding to permit free access of personnel during operations. These are delimited by posted signs, gates, audible alarms, or by red and green lights. When the red light is on, access into that area is prohibited.

1.4 Administrative Control connotes those practices in nuclear safety depending upon adherence to specified conditions or restrictions during handling or storing of fissile materials.

2. PRACTICES

2.1 The safety and operational procedures of each experiment program involving fissile materials shall be established jointly by the supervisor of the Facility and at least one other Senior Experimenter.

2.2 One Senior Experimenter shall be in charge of a particular experiment. A minimum of two persons, one of whom is an Experimenter or a Senior Experimenter, shall be present during any experiment or operation with fissile materials.

2.3 The primary concern of the person in charge of any operation shall be the maintenance of personnel safety.

2.4 Any deviation from an established experiment program shall be reviewed by at least two Senior Experimenters.

2.5 During operating periods red signal lights shall designate inadequately shielded areas within the perimeter fence from which all unauthorized persons shall be evacuated before remote operations are begun.

2.6 The number of persons, including visitors, present in the control room during an experiment shall be at the discretion of and subject to the direction of the Senior Experimenter in charge.

2.7 All fissile material in the Facility is under administrative control. Senior Experimenters shall be responsible for the loading and adjustment of assemblies and for the safe transfer and storage of fissile materials. All procedures shall be based on experimental results or shall be in accord with accepted practices and shall be approved by the Laboratory's Criticality Committee. At least two persons, one of whom is a Senior Experimenter or an Experimenter, shall be present during transfer of fissile material within the Facility.

III. HISTORY OF CRITICAL EXPERIMENTS IN OAK RIDGE

Early Experiments

The history of critical experiments at the Oak Ridge National Laboratory dates back to late 1945 when a series of measurements was made on assemblies of a fluorocarbon-uranium oxide mixture in which the uranium was enriched to 24% in ^{235}U. The assemblies were moderated and reflected by hydrogen. A second set of experiments, consisting of tubes containing a heavy water solution of $U(95)O_2F_2$[a] latticed in a tank filled with heavy water, was performed during the spring and early summer of 1946.

An extended program of experiments, supporting the design of the Materials Testing Reactor, was conducted in 1947 and 1948. Aluminum tubes which contained an aqueous solution of ^{235}U-enriched uranyl fluoride were latticed in a tank which could be filled with water. Natural water, heavy water or beryllium served as a neutron reflector.

These early experiments were conducted in cells in the plutonium recovery building presently designated as 3019, X-10 Area, which were modified, at least for the latter series, to provide a 2-ft-thick shield between the controls and the assembly.

In a concurrent program, planned in late 1945, measures were made of the critical dimensions of materials having nuclear properties similar to those of uranium hexafluoride. The purpose of these experiments was to provide bases for the safety of the Oak Ridge Gaseous Diffusion Plant. The first experiments in this series were performed at the Los Alamos Scientific Laboratory in the spring of 1946 for the dual purpose of training personnel and of acquiring some data from fluorinated uranium compounds of high ^{235}U content. Experiments with fluorinated uranium compounds in solid form were inaugurated in Oak Ridge in late summer 1946 with what was probably the first equipment to be used for the remote operation of experiments with solid fissile material. This work, performed in a small laboratory near the Gaseous Diffusion Plant, was followed in 1947 by experiments with solutions of uranium salts which continued until mid-1950 when the present Facility was completed.

Experience at Building 9213, Y-12

The extremely wide variety of experiments and experimental materials which have come under study in the various programs during more than a decade at the Critical Experiments Facility cannot be described in any

[a] U(95) is a designation of uranium enriched to 95% in the ^{235}U isotope.

summary report of this kind within reasonable bounds of effort and space. The history of Building 9213 can be meaningfully organized by showing the variety of experience with fissile material that has been acquired rather than by enumerating the individual experiments. There are only two basic types of critical experiments: those controlled by careful additions of liquids (fissile solutions, moderator or reflector) and those controlled by the addition of solids. There are also, of course, many examples of combinations of the two types.

Experiments typical of those with liquid fissile material have used uranyl fluoride and uranyl nitrate solutions in a continuing program, inaugurated in this Facility in 1950, whereby the critical parameters of spherical, cylindrical, slab, and annular geometries have been measured. These experiments have formed the bases for many nuclear safety specifications and for special problems in the processing of enriched uranium in chemical plants. A part of this program has contributed to basic reactor physics through a better understanding of the neutron leakage and by measurement of the fission neutron yield of ^{233}U and ^{235}U.

Experiments typical of those with solid materials have been performed in many programs. For the Aircraft Nuclear Propulsion Project, for example, many experiments were performed with heterogeneous combinations of uranium, beryllium, graphite, Teflon, and Plexiglas, of which some were reflected by graphite, beryllium, or Plexiglas. Experiments with homogeneous materials have been performed in other programs using blocks of mixtures of CF_2-UF_4 and $C_{25}H_{52}$-UF_4.

Other solid-material experiments have been performed with unmoderated ^{235}U-enriched uranium metal. Single cylinders, slabs, and spheres have been made critical both unreflected and with reflectors of graphite, beryllium, and Plexiglas. Preliminary experiments performed on unreflected uranium-molybdenum alloy to establish the design of the Health Physics Research Reactor also fall in this category. The latter experiments were followed by a complete check-out of this reactor's performance and instrumentation, including super-prompt-critical operation with the production of energy pulses of up to 1.7×10^{17} fissions.

In addition to these experiments with unmoderated uranium, arrays of metal cylinders and slabs have been made critical, with and without hydrogeneous moderator between the units; some of the arrays were also reflected. The ^{235}U enrichment of the uranium for individual experiments ranged from 0.94 to 93%.

Several combination-type experiments have also been performed for reactor projects. Those for the Army Package Power Reactor, for example, utilized stainless steel fuel plates and were water-moderated and -reflected. The unique geometry of the Tower Shielding Reactor II was first investigated rather crudely with available materials and later, much more thoroughly, with the first reactor core fabricated from that design. The High Flux Isotope Reactor Critical Experiment No. 1 was an exploratory series of experiments with four liquid regions of which one was a heavy water reflector. Subsequent experiments in this series were with more accurate nuclear mock-ups of the reactor, complete with target, U-Al alloy fuel element, controls, water moderator and beryllium side reflector. Also included in this group of experiments are two high temperature (1300°F) molten salt (ZrF_4-UF_4-NaF) reactor experiments which had internal and external beryllium reflectors.

There have also been a number of experiments with uranium solutions containing either copper or boron to establish the safety of certain chemical operations. Other water-moderated and -reflected experiments with fuel elements from pool-type reactors, from the Experimental Gas Cooled Reactor, from the Heat Transfer Reactor Experiment, and from the Savannah River and Hanford Reactors have aided the solution of many related criticality problems.

The Facility is equipped with a few major pieces of apparatus, described later, with which most of the experiments have been performed; in other cases the apparatus was supplemented by components specifically designed for a particular program.

IV. DESCRIPTION OF THE FACILITY

Location

The Critical Experiments Facility is located at a remote site in the southwest portion of the Y-12 Area. It is situated in a pocket in the terrain formed by surrounding hills as much as 200 ft higher than the building itself. The projected distance to nearest work areas is more than 2000 ft and to the nearest public highway is 4200 ft. The Facility is enclosed in an area to which access is restricted by a chain link fence. Gates in the fence, except the one at the entrance to the Facility, are kept locked. Many of these features are shown in Fig. 1, a plan of the area including elevations. Figure 2 shows the immediate building environment in greater detail.

Construction

The Facility is a two-story concrete and concrete block structure about 200 ft long and 80 ft wide. The west and east ends of the building are shown in Figs. 3 and 4, respectively. Floor plans of the building are included in Fig. 2.

The three[b] assembly areas or test cells extend the full height of the building, i.e., about 35 ft, and each has a floor area between 900 and 1520 ft^2. A control room is associated with each cell and is separated from it by a 5-ft-thick ordinary concrete wall having a specific gravity of about 2.5. Visual communication between the control and test areas is provided by water-filled windows or by closed circuit television; verbal communication is provided by an intercom. Necessary office, laboratory, and other supporting space is located in the central portion of the building.

The walls of the test cells on the south side of the building adjacent to the roadway are of 5-ft-thick concrete. The cell walls on the north side are 12 to 18 in. thick, established by structural needs, and provide significant radiation shielding at the boundary of the area defined by the perimeter fence located at least 50 ft distant.

The walls on the east and west sides are also only 12 to 18 in. thick, for structural purposes. Personnel on the roadway and in other accessible areas are protected from leakage radiation through these walls by earth bunkers and additional concrete walls shown in Figs. 2-4.

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[b]The original construction included only two assembly areas on the east and west sides. The third, separated from the east cell by a 5-ft-thick wall, was added in 1957.

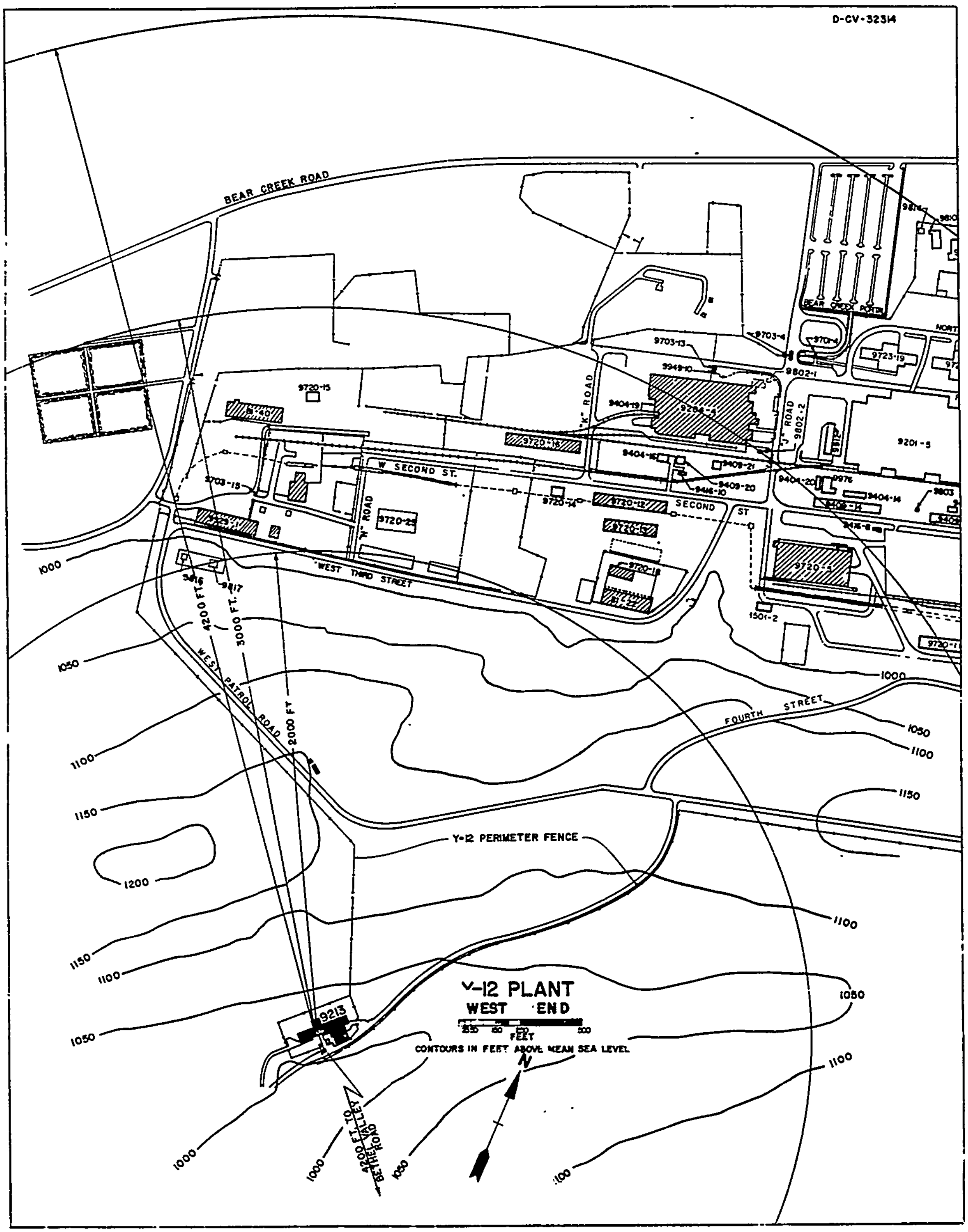

Fig. 1. Y-12 Plant, West End.

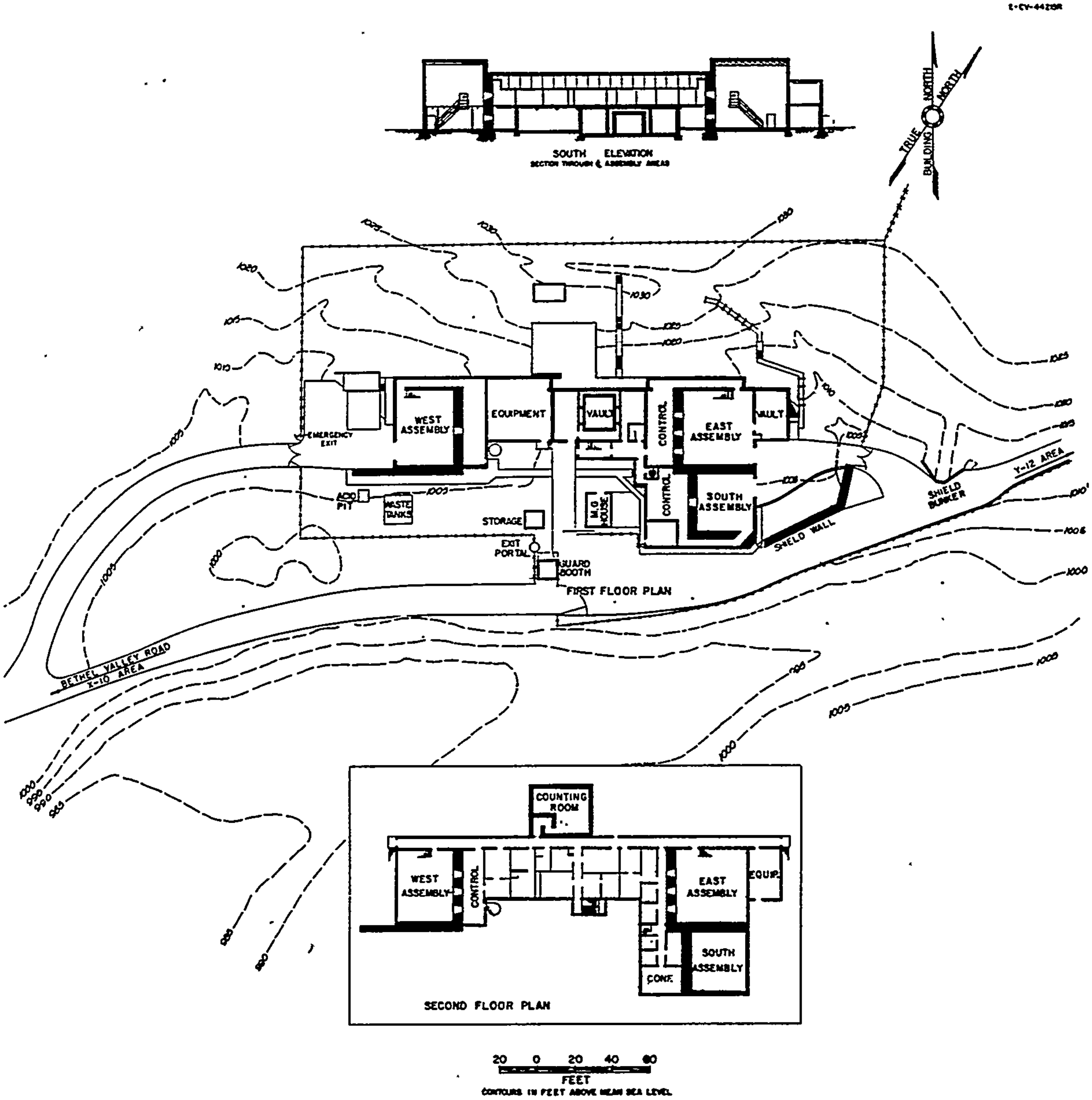

Fig. 2. Plans, Elevation, and Contours, Building 9213

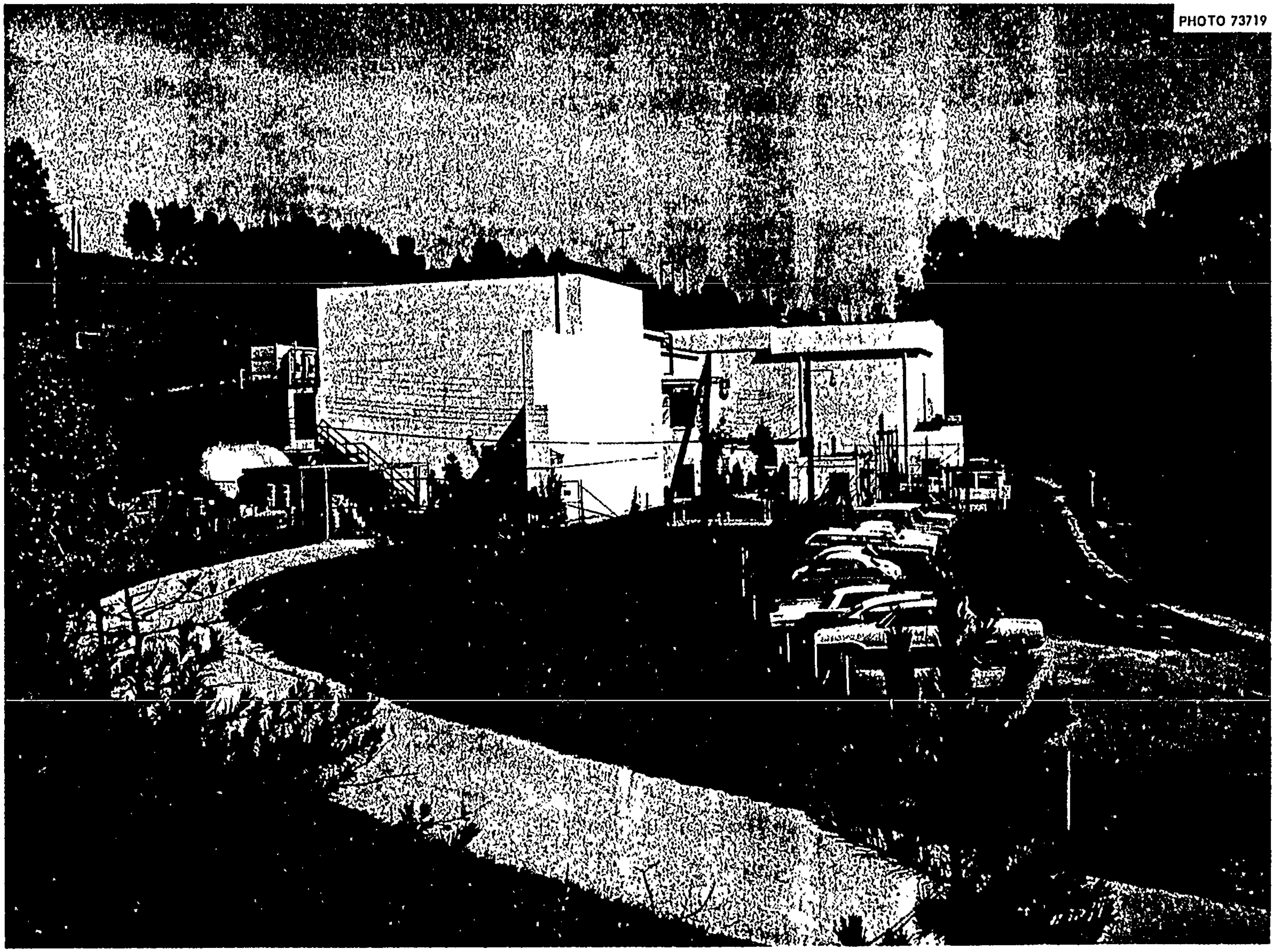

Fig. 3. West End of Building 9213 Showing the Concrete Shielding Wall Between the Roadway and the Large Doors.

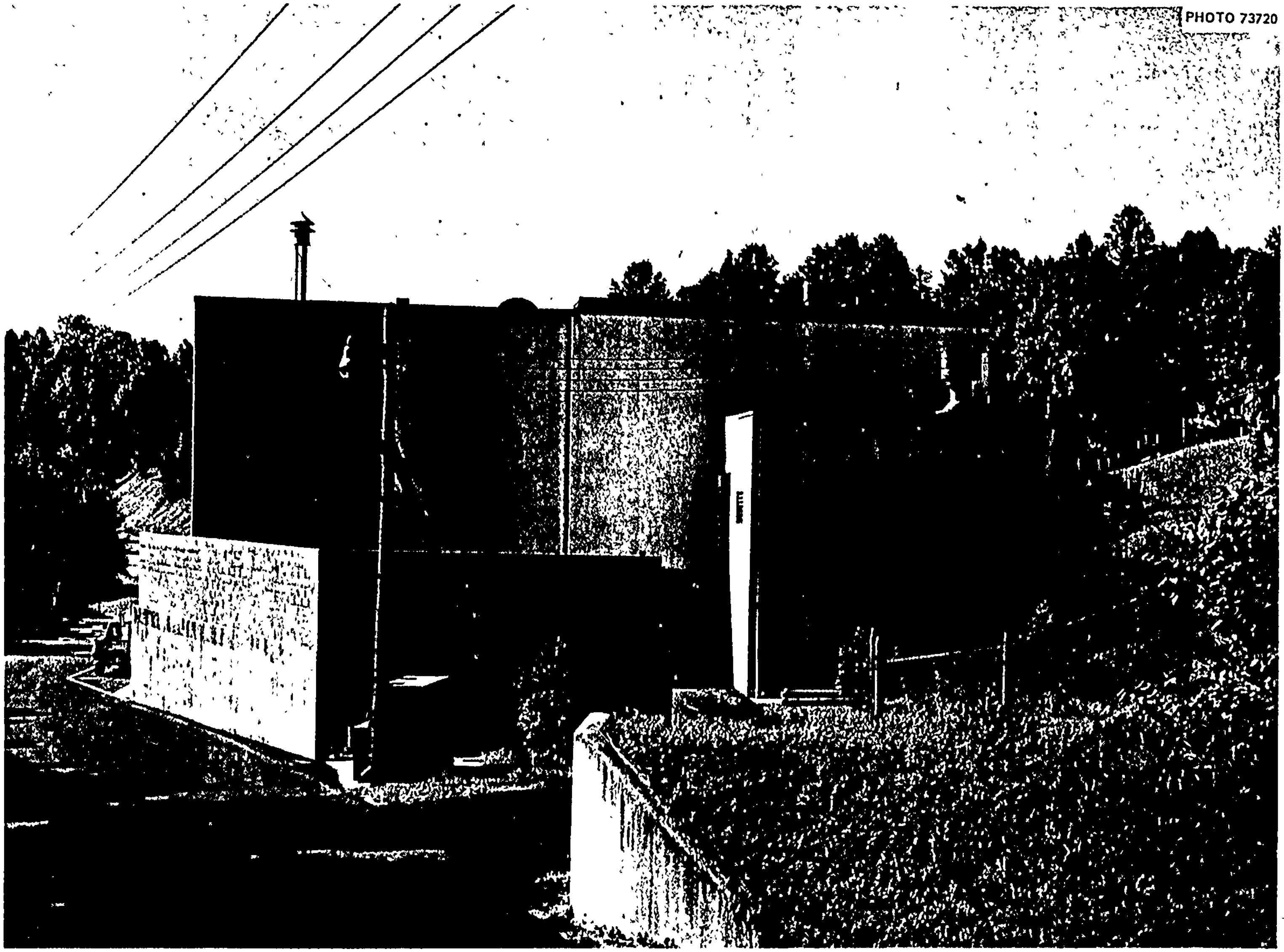

Fig. 4. East End of Building 9213 Showing the Concrete Walls and Bunkers which provide Shielding.

Measurement has shown that this shielding provides adequate protection against exposure to projected radiation sources.

Many other features were incorporated in the design to improve overall personnel protection. In some places, for example, windows were substituted for solid walls where the latter would have back scattered radiation into normally occupied areas.

The scattering of radiation by air was underestimated at the time of the design of the building and, as a consequence, the original roof met structural requriements only. The need for shielding against air scattering was later recognized and at the present time, either by addition to the original structure or by inclusion in the design of the new area, each test cell is covered by a 1-ft-thick concrete slab. The intermediate general-purpose area and the guard shelter are covered by concrete at least 3.5 in. thick. In practice, of course, the effective thickness of these roof shields is somewhat greater because of the angle at which the radiation must traverse them in order to be scattered into the central area or onto the road.

Reference is made to the drawings and specifications of the architect-engineer for structural details.[2]

Many data, amassed over the ensuing years from both accidental supercritical excursions and planned experiments, yield an evaluation of the protection of personnel afforded by these structural features. More detailed reference to these supporting data will be presented in the discussion of potential incidents. In summary, however, it may be said that the shielding provided is adequate to limit personnel exposure from radiation sources of maximum expected intensity in the three cells to the levels specified in US AEC Manual Chapter 0524. During operations personnel are located in shielded areas; their exclusion from nominally unshielded

2. Giffels and Vallet, Inc., Detroit 26, Mich. Job 48-148A, completed 1950; Barber and McMurray, Knoxville, Tenn. Contract 81Y-34807, completed 1957; UCNC Dwgs. E-CV-23227, E-S-24228, E-S-24229, E-S-24230, E-S-24420, E-HV-23275, completed 1958. These drawings and specifications are available from Union Carbide Corporation, Nuclear Division, Y-12 Plant, Engineering Division, Oak Ridge, Tennessee 37830.

areas is enforced by the perimeter fence and by rigid administrative controls supplemented by alarms which sound in the affected control rooms.

Ventilation

The building is air conditioned. Each of the three cells is heated and ventilated by air circulated and conditioned in a system serving that cell exclusively. Contamination arising in one area, therefore, is not directly carried by an air stream into another area of the building. It is further provided that all air handling equipment in the building is automatically stopped upon signal from high level radiation detectors in each cell so that the contaminated air remains stagnant until such time as it is deemed appropriate to reactivate the air handling equipment. This reactivation must be done manually. In addition to the usual air conditioning system, each cell is equipped with a fan having a capacity of 800 to 1000 cfm which normally runs continuously and discharges to the atmosphere. This outflow of air maintains the pressure within the cell slightly below that in adjacent areas of the building and also below that of the ambient atmosphere. Thus, at least in the short interval required for air pressures to equilibrate after stoppage of the fans upon emergency signal, the flow of air is into the potentially contaminated area. Subsequently, any contamination can be discharged to the atmosphere either by the small fans or by large exhaust blowers, each having a capacity of at least 10,000 cfm, with which each cell is equipped. Appropriate louvers open as the blowers start in order to provide free and rapid exhaust of any airborne contamination. Filters are not installed in these exhaust systems since personnel can be readily controlled in the remote area in which the Facility is located. Little, if any, inconvenience would be forced on other areas by such a procedure. Operations within the Facility are not contingent upon operability of the ventilating system.

Beyond that which has already been described, there is no provision for containment of airborne activity. The Facility may be inadequate for the risks which might arise in experimentation with uncontained highly toxic materials. Should the use of materials more toxic than uranium become desirable, a more complete evaluation of contamination potentials may make it necessary to install in existing cells primary containment structures similar to those successfully used routinely in plutonium production operations.

Contaminated Waste Collection Tanks

To guard against loss of fissile materials, the liquid waste drains from laboratory areas lead first tc an acid-neutralizing pit thence to hold tanks which are emptied only after analyses have shown permissive quantities of fissile material present. Incidentally, no concentration even approaching that economically salvable has ever been collected in these tanks. Large, possibly critical, quantities of fissile material cannot unknowingly flow into the waste tanks because the drains leading to them are either above floor level or are fitted with gasketed pipe caps.

V. EQUIPMENT AND EQUIPMENT OPERATION

The Facility is equipped for experiments of all kinds with uranium as both liquids and solids. These may range from test vessels containing aqueous solutions of enriched uranium, with or without an aqueous reflector, to tests of massive pieces of unreflected uranium metal.

In all cases the approach to criticality is by the addition of reactivity through the remote operation of some device from the shielded control area. This device, for example, may be a pump for liquids or it may be an hydraulic or mechanical drive to bring sections of a solid assembly together. Reactivity may be removed by similar actions in reverse, [redacted] In addition to this normal operation, reactivity may be more rapidly removed by similar actions in response to signals generated in appropriate detectors when a preselected radiation field is exceeded. This desired emergency shutdown is always produced by two mechanisms.

A fundamental design premise dictates that the inherent rate of reactivity addition cannot be altered at a control console as a result of an on-the-spot decision of the operator. It follows, as a corollary, that uncertainty in the rate, which might result from ignorance of alterations in the immediate past, is minimized. On the other hand, the operator is required to exercise his judgement in the modus operandi of the controls which alter the reactivity. He may, for example, open a valve for an extended time when a system is known to be far from criticality whereas he may open it for only a fraction of a second when near criticality. In both cases the rate of flow of the liquid is the same while the valve is open, whereas the actual rate, averaged over the time to achieve criticality, may be many factors of 10 less. The maximum available rate may be a function of the position of the moving parts, being altered by appropriate limit switches in the equipment itself. It is emphasized that, in the detailed description of equipment which is to follow, the time rates of maximum reactivity addition are those established by the characteristics of the equipment, not by operator action. Actual rates may, therefore, vary up to those cited.

A neutron source of strength appropriate to the experiment is always proximate to the fissile material during its initial assembly. The source is a driver for the neutron multiplication. It may be an encapsulated mixture of plutonium and beryllium or of polonium and beryllium, the spontaneous fission of ^{238}U, or a nuclear reaction within the test materials. Provision is made for removal of encapsulated sources from assemblies expected to become critical in order to truly establish criticality.

The experiments performed in the Facility can be broadly classified by the phase of one or more of the prime materials utilized; these phases are, of course, solids and fluids. Solid materials are assembled by remotely controlled motion of one or more sections either in horizontal travel or in vertical travel. Fluid materials are moved remotely by pumps or by gravity through connections between storage and test vessels. Experiments of these two classes are presently performed with equipment exemplified by that to be described. The description does not include the details of all of the past and certainly will not completely encompass the future. The apparatus and procedures represent design criteria and operational practices proven to be satisfactory. Although future experiments may differ in purpose, intent, and material, they will follow this basic pattern.

Only in extremely infrequent and exceptional instances should further description be necessary for purposes of satisfying requirements for a safety evaluation.

Criticality Testing Unit, Vertical Displacement.

The equipment used for assembling solid materials by vertical motion is typified by the Criticality Testing Unit (CTU) which was designed primarily for critical experiments on compact, unmoderated assemblies. The vertical separation of components can be accomplished by two means and is the usual method for reducing reactivity.

The CTU, shown in Fig. 5, consists primarily of two tables: a fixed table which is manually adjustable in elevation, and a vertically movable table powered, through a magnetic coupling, by a pneumatic-hydraulic system. The fixed table, which constitutes the upper section of the unit, is a metal plate or membrane supported by vertical legs at the corners of a 4-ft square. The dimensions of this member are appropriate to the particular experiment. Its adequacy is shown by structural analyses or by loading, with inert material, in excess of that mass to be imposed in the experiment. The movable table is an 18-in.-diam by 1-in.-thick stainless steel plate attached to the magnet housing. The equipment is shown schematically in Fig. 6 and a control block diagram is shown in Fig. 7.

In use, a part of the assembly is mounted on the upper table and the remainder is mounted on the movable table. The lower section of the assembly is raised toward the upper section by remote operation. In some experiments the lower section of the assembly rests upon a low-density structure mounted on this table in order to reduce neutron reflection.

During normal operation the magnet is energized and the movable table follows the motion of the hydraulic cylinder piston. Contact between the magnet and the table is shown by a light on the console. An interlock demands the table be lowered if there is no contact. Further, a selsyn on the console indicates the position and motion of the movable table, not that of the piston; therefore, if the interlock fails and the magnet is not energized and if the switch driving the piston upward is activated, there will be no indication of motion until the top of the piston makes contact

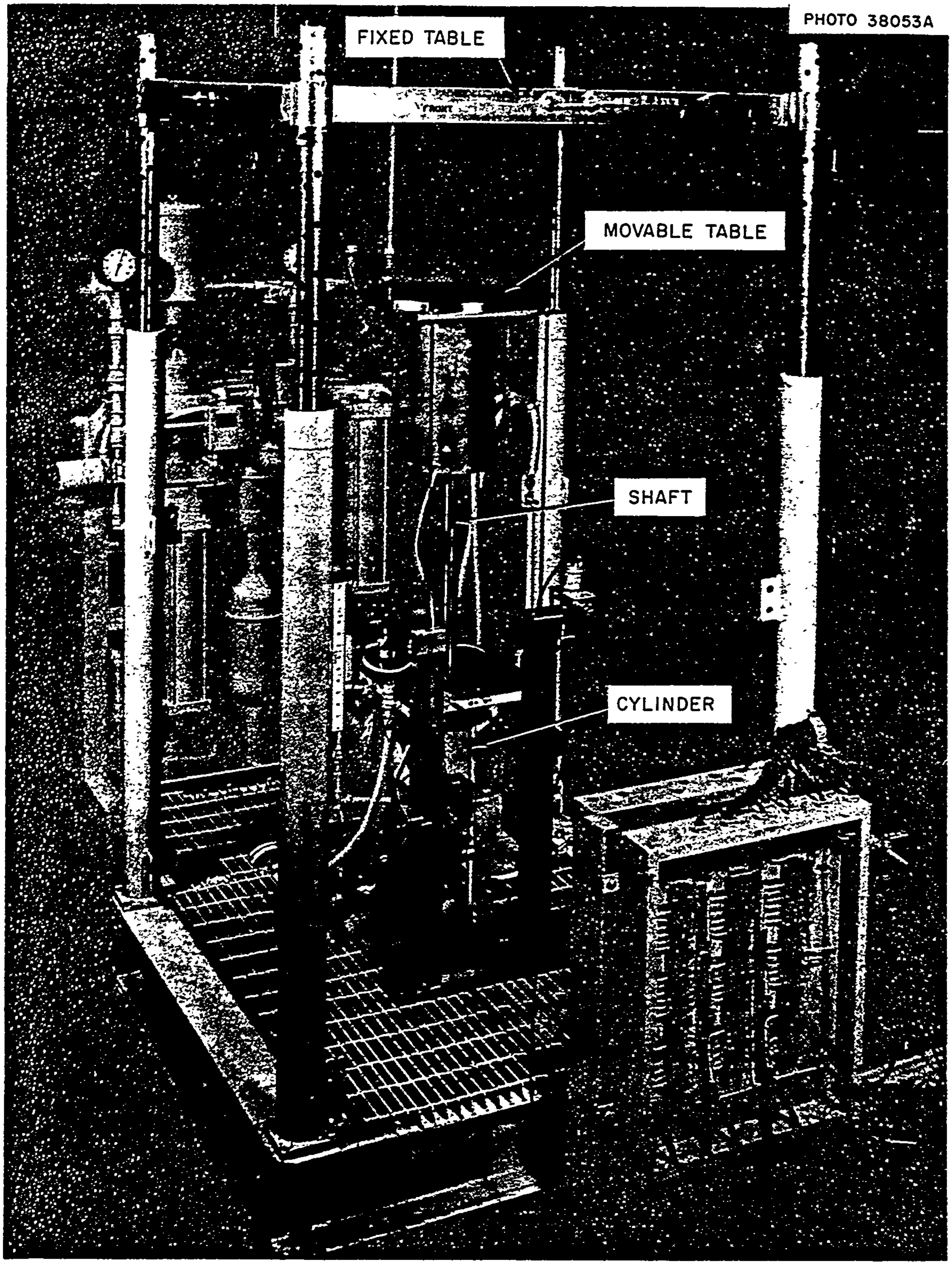

Fig. 5. The Criticality Testing Unit, Vertical Displacement.

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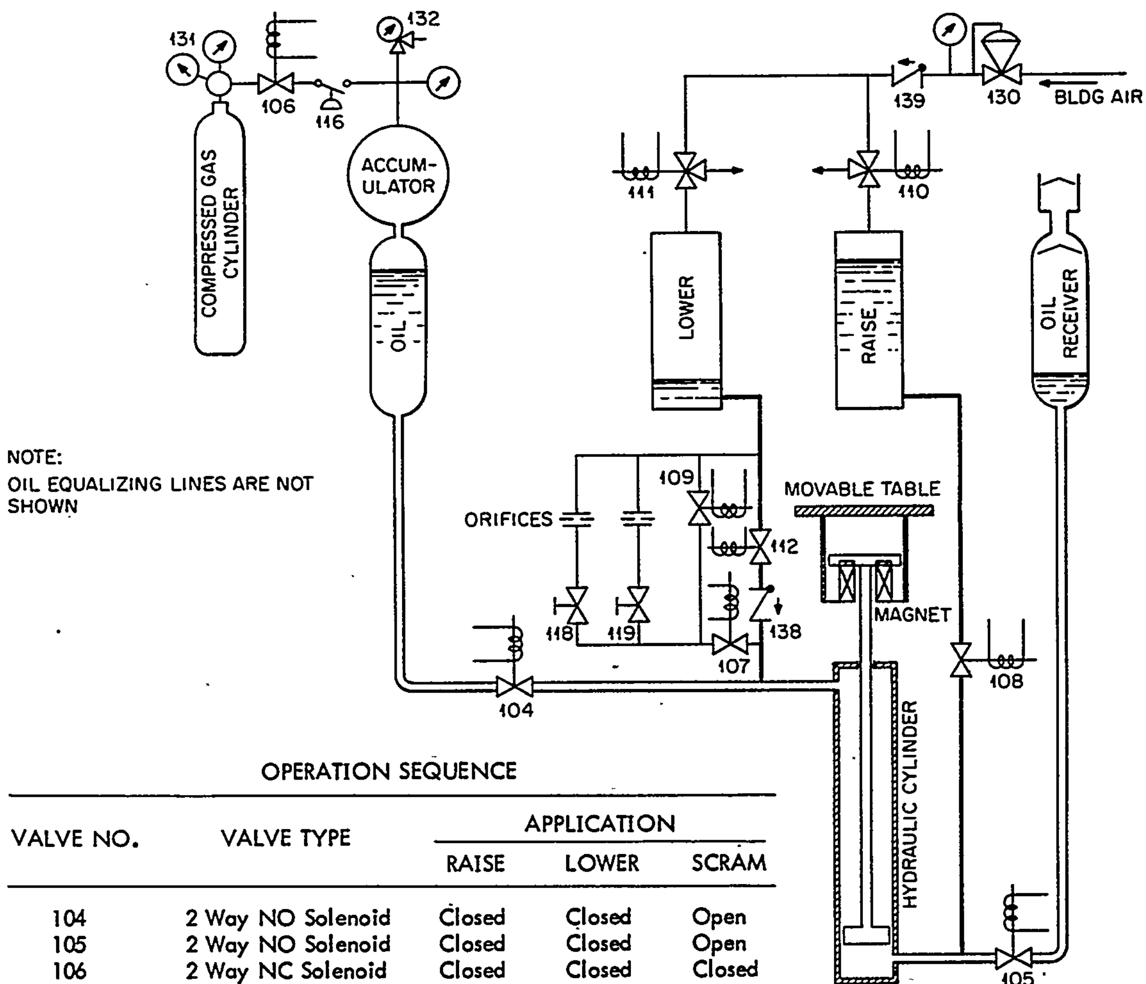

OPERATION SEQUENCE

VALVE NO.	VALVE TYPE	APPLICATION		
		RAISE	LOWER	SCRAM
104	2 Way NO Solenoid	Closed	Closed	Open
105	2 Way NO Solenoid	Closed	Closed	Open
106	2 Way NC Solenoid	Closed	Closed	Closed
107	2 Way NC Solenoid	Open	Closed	Closed
108	2 Way NC Solenoid	Open	Open	Closed
109	2 Way NC Solenoid	Open*	Closed	Closed
110	3 Way NC Solenoid	Open	Exhaust	Exhaust
111	3 Way NC Solenoid	Exhaust	Open	Exhaust
112	2 Way NC Solenoid	Closed	Open	Closed
116	Pressure Switch			
118	Manual Needle	Allows Orifice Selection		
119	Manual Needle	Allows Orifice Selection		
130	Pressure Regulator	0–90 psig		
131	Pressure Regulator	0–500 psig		
132	Pressure Relief	400 psig		
138	Check			
139	Check			

*Except for slow raise through orifices.

Fig. 6. Schematic of Criticality Testing Unit, Vertical Displacement.

NOTE: Information flows only horizontally
along the information paths, never
top of the sheet.

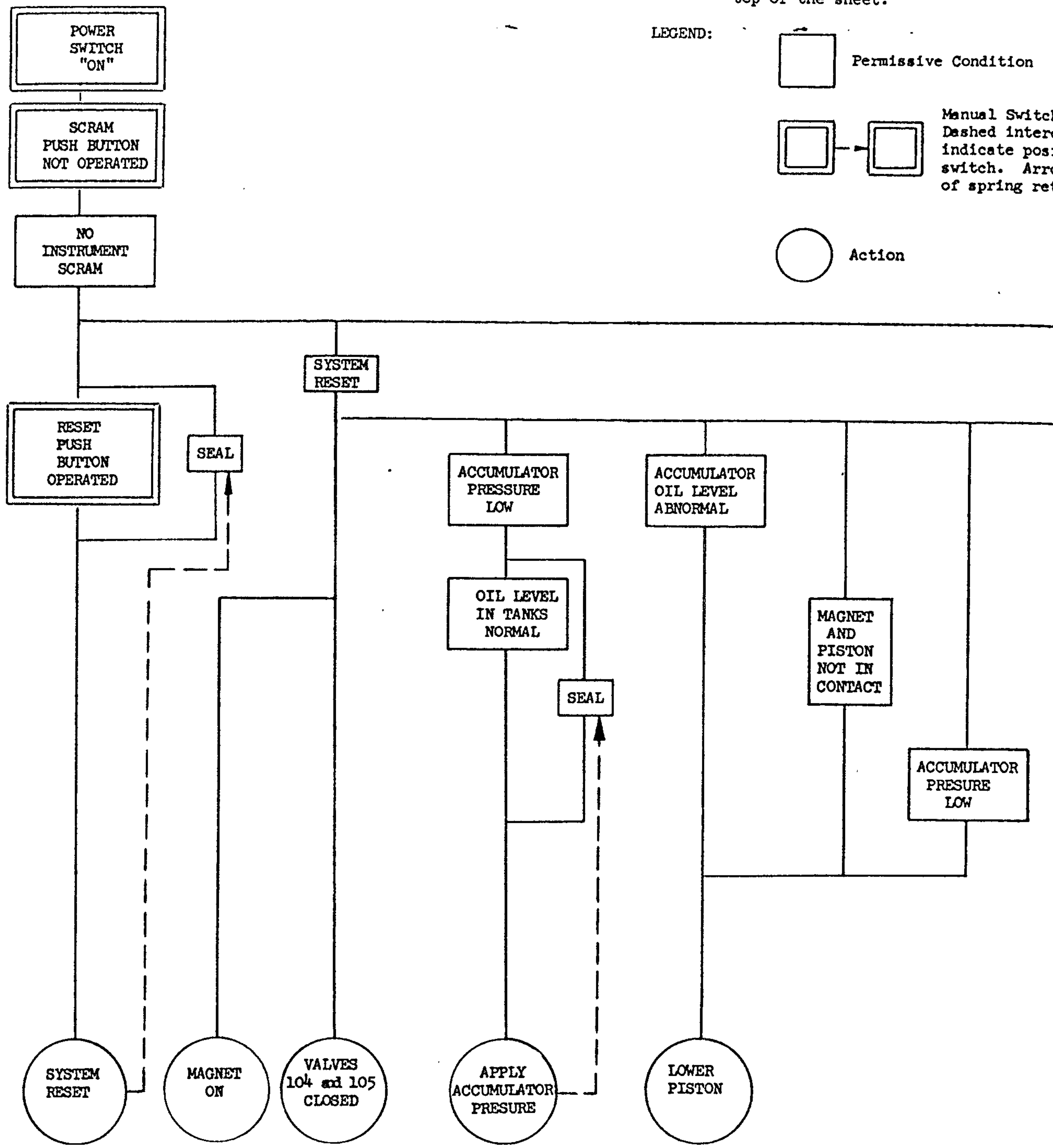

Fig. 7. Control Block Diagram
Displacement.

nd downward
toward the

nnecting lines
ions of same
shows direction
rn.

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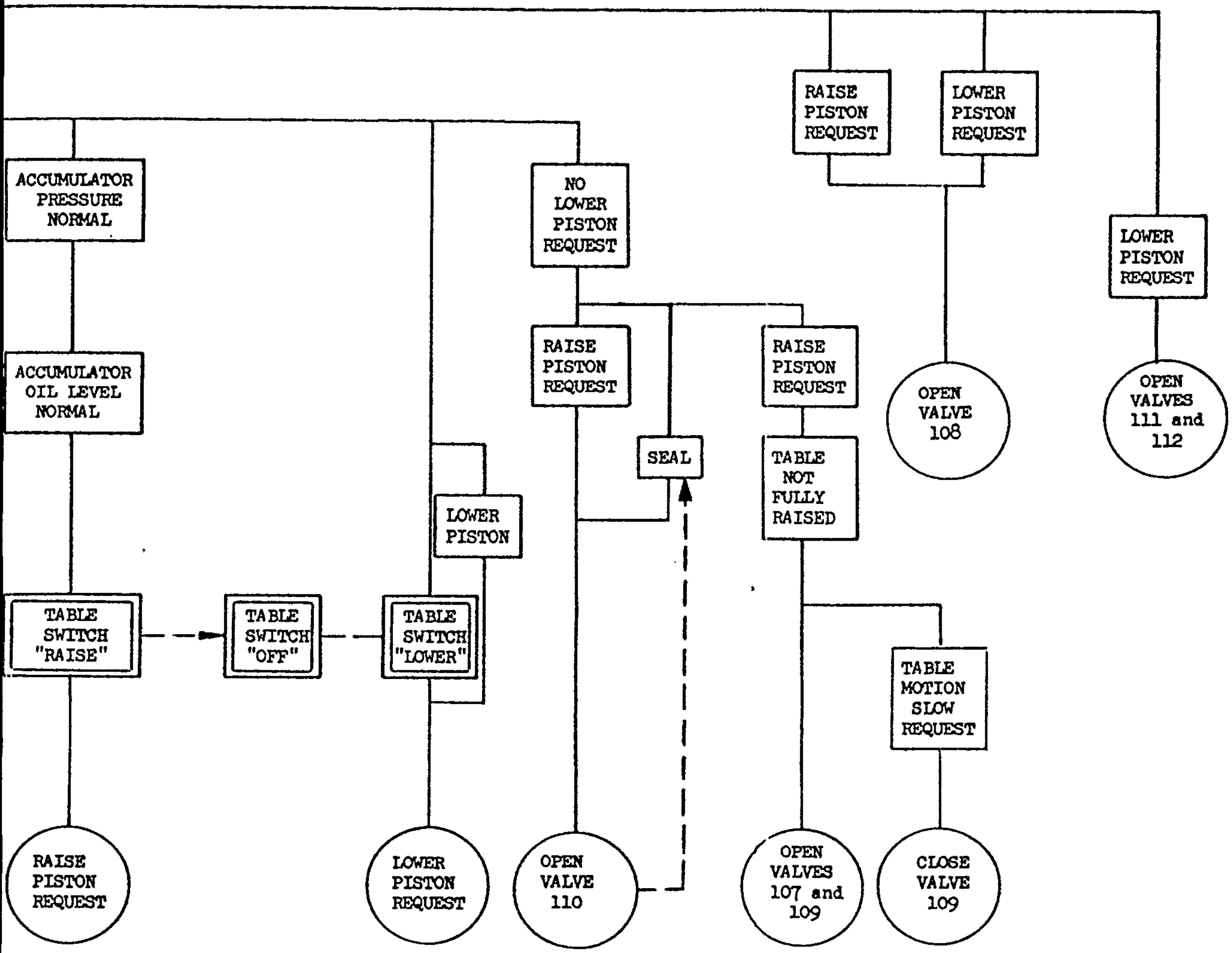
See Fig. 6 for valve identification.



Criticality Testing Unit, Vertical

with the bottom of the table, an interval of about 30 sec. The operator will thus be aware of an abnormal condition.

Full travel of the movable table is 24 in., at a maximum lift rate of 20 in./min without load. At a preset position in its travel the moving member operates a switch which closes a valve diverting the flow of the hydraulic fluid through a system consisting of two orifice plates in parallel, each with its own manual shutoff valve. In designing an experiment, selection is made of the desired closure rate and the appropriate flow is thereby established. With no load on the table a typical flow through one of the two orifices allows a closure rate of 0.15 in./min and flow through the other allows a rate of 0.25 in./min. Simultaneous flow through both orifices permits a rate of 0.40 in./min. The minimum lowering rate of the table for normal shutdown is 40 in./min and exceeds the maximum lift rate by a factor of two. Present magnet characteristics limit the load on the movable table to 500 lb. With this load the maximum lift rate is reduced to ~ 10 in./min and the separation rate under normal conditions is 58 in./min.

The safety feature of the CTU, the separation of the components of the assembly, is effected in two ways. When an emergency condition occurs, the magnet is de-energized and the platform drops at least 6 in. under gravity. Separation of the sections of the assembly may also be brought about by a reversed hydraulic force on the piston, provided by oil under high pressure supplied by compressed gas as shown in Fig. 6, which moves the piston through its total downward displacement in less than 2 sec. A characteristic emergency performance curve is shown in Fig. 8. In that particular test the table moved freely under gravity for the first 9 in. of travel at which time contact was made between the table and the top of the piston rod; the ensuing motion was governed by the hydraulic system. The downward motion began about 35 msec after initiation of the signal to the electrical circuits. This delay depends, of course, upon the load and the magnet current. (Minimal release time can be achieved for a particular load by adjusting the magnet current to the minimum required to support the load; a value as low as 18 msec has been measured.) The rate of component separation, upon emergency signal, was about 12 in./sec over the

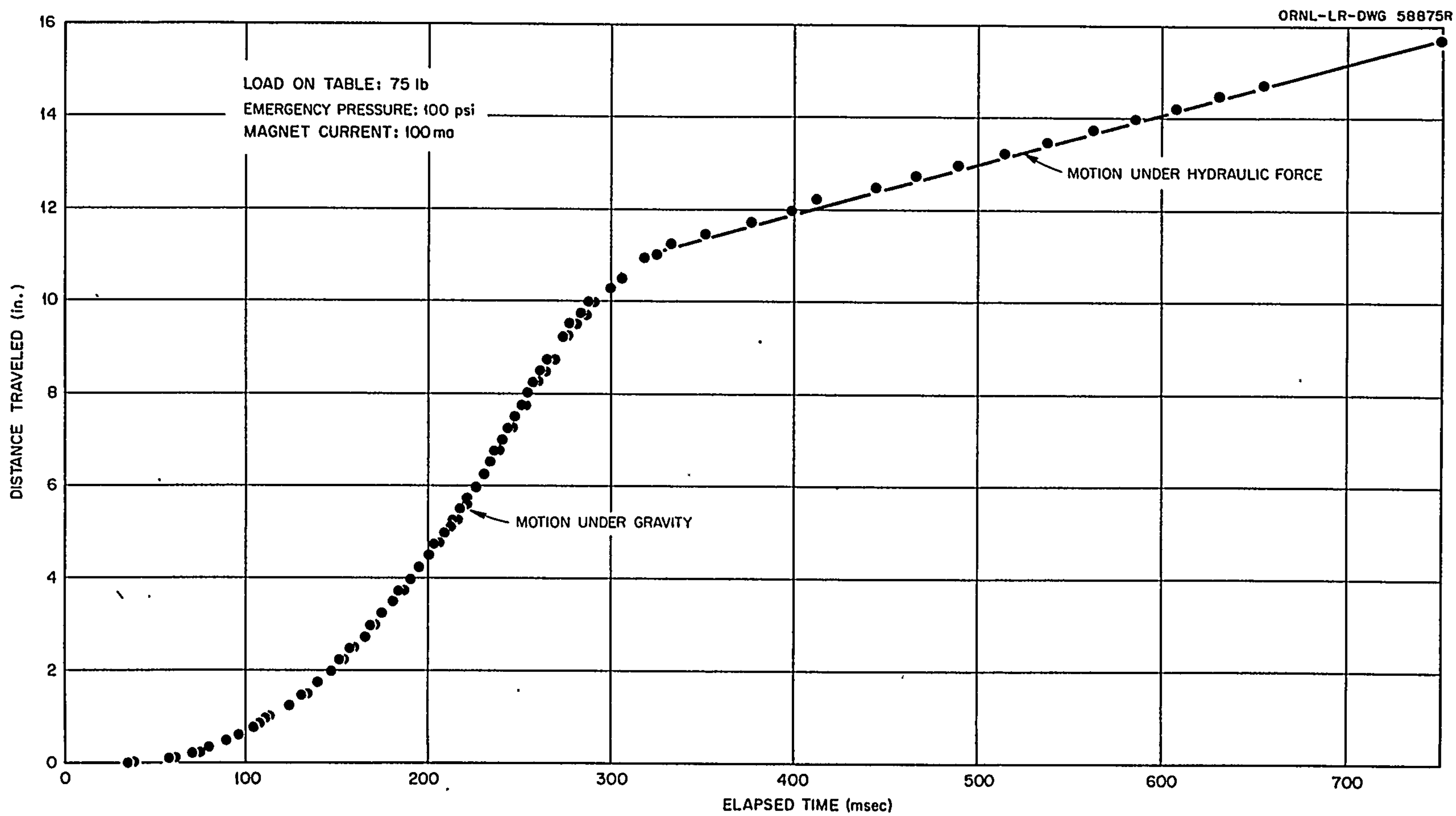


Fig. 8. Characteristic Emergency Performance Curve of the Criticality Testing Unit, Vertical Displacement.

first inch of travel, 60 in./sec for the next 9 in., and 10 in./sec for the remainder of the downward stroke. Initial accelerations greater than 1 g are possible through the hydraulic action, although in experiments in which the assembly consists of simply stacked components such rapid motion undesirably disturbs the assembly, particularly during test of the safety system prior to starting operations each day that experiments are to be initiated.

The magnet current and the rates of motion of the table are adjusted to conditions of maximum safety commensurate with the experiment under study.

Provision is also made in the CTU whereby an assembly can be prepared in three sections. In this case the center section is placed on the upper table and the lower one is mounted on the movable table. An upper section is positioned by an air operated piston or by other suitable means such as a cable-pulley arrangement; however, criticality is achieved by motion of the lower table as described above.

The time rates of reactivity change, derivable from the above speeds, are characteristic of particular assemblies. In one assembly of U(93) metal, for example, the sensitivity near closure was the order of 10 dollars/in., which was equivalent to a time rate of reactivity increase of 1.6 cents/sec at the slowest speed of approach. Advance from delayed to prompt critical under these conditions would require 1 min. In normal shutdown the initial rate of reactivity decrease was about 6 dollars/sec. In emergency shutdown the average rate of reactivity decrease over the first inch of travel was 120 dollars/sec. A reactivity decrease of 7.5 dollars had occurred 100 msec after the emergency signal.

A typical experiment performed with the CTU proceeds somewhat as follows. After verification that the behavior of operational instrumentation and safety devices is satisfactory and that a neutron source is appropriately located, a subcritical unit of fissile material is placed on the movable table and another, well aligned vertically with the first, is placed on the fixed table as shown in Fig. 9. The lower unit is raised toward the upper unit by operation of the drive mechanisms from the control room. Having established that two unreflected units are subcritical, a

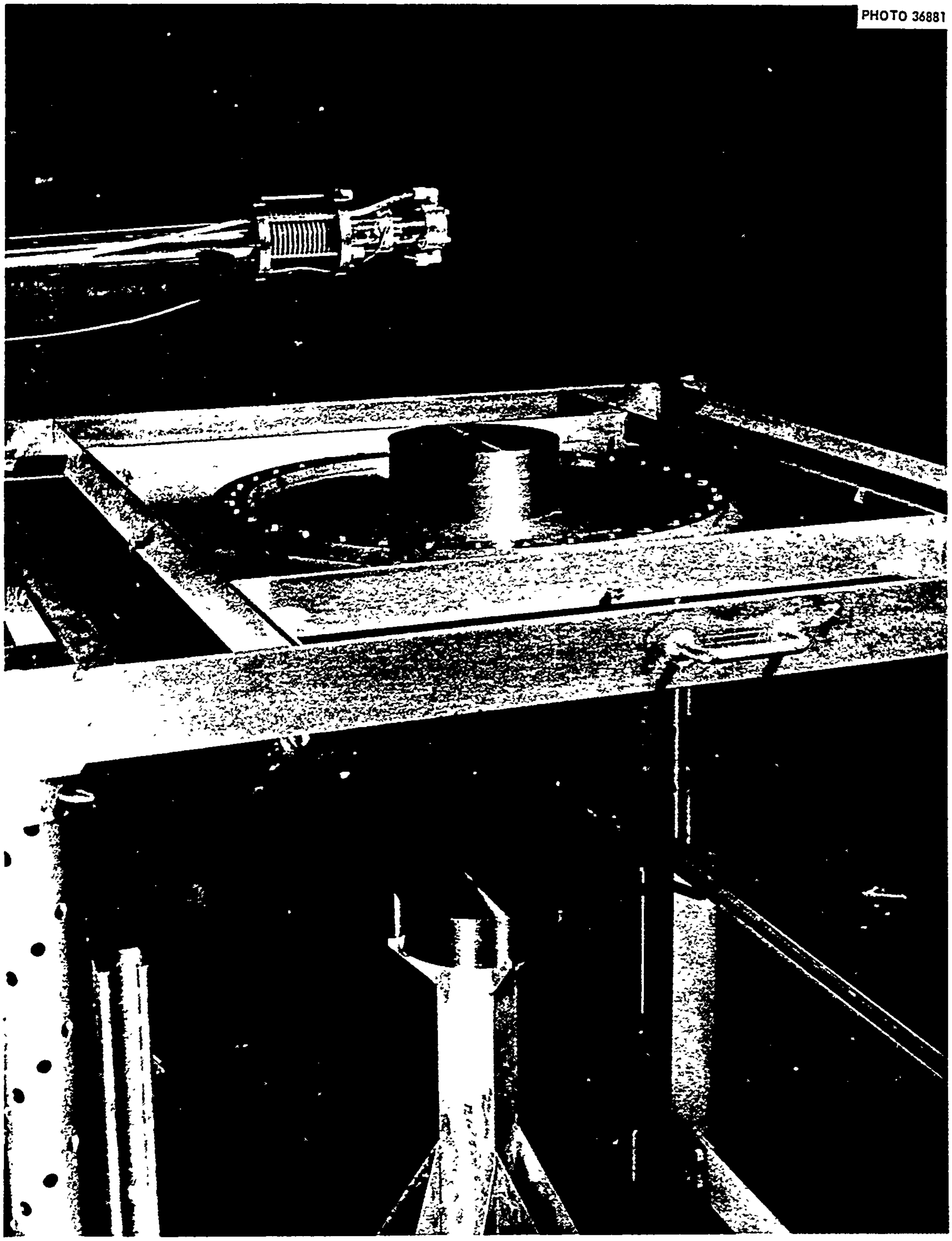


Fig. 9. Assembly of Uranium Metal Mounted on the Criticality Testing Unit, Vertical Displacement.

small piece of solid hydrogenous material, simulating the neutron reflecting properties of a pair of hands, is added to the assembly and the above measurement repeated. If this combination is subcritical, a second unit can be safely added to, say, the upper table and the procedure repeated. Continuation of this step-by-step process leads to a near-delayed-critical configuration, perhaps a little subcritical, perhaps a little supercritical, by amounts depending upon the size of the increments of reactivity which are available.

The test of the reactivity of the assembly is, of course, the observation of the time behavior of the neutron population upon the removal of the start-up neutron source or its domination by fission neutrons.

As stated above, the CTU was designed for experiments primarily with solids including uranium metal, uranium oxide, graphite, beryllium, potassium, tungsten, iron, stainless steel, and hydrogenous substances such as paraffin, polyethylene, and methyl methacrylate. On occasion liquids in sealed containers are used.

Criticality Testing Unit, Horizontal Displacement.

The Facility utilizes two pieces of equipment, designed to be operationally identical, whereby components of an assembly are brought together by horizontal displacement. These are usually referred to as "split tables." Each piece of equipment consists of two tables, in the same horizontal plane, one fixed and the other movable to a separation of 54 in. or more from the fixed one. All tables are designed for a maximum deflection of 0.005 in. under a load of 2000 lb. In one pair the stationary table is 6 x 6 ft and the movable one is 4 x 6 ft. In the other pair, both tables are 4 1/2 x 6 1/2 ft, the latter dimension perpendicular to the direction of travel. Figure 10 is a photograph of one of the split tables.

The following description of operation applies explicitly to one of the split tables. It is expected that the behavior of the second, when put into service, will be identical. In this description reference is made to Figs. 11 and 12.

The movable table is firmly fastened to the piston rod of a combination pneumatic-hydraulic cylinder which is the prime mover for the complete

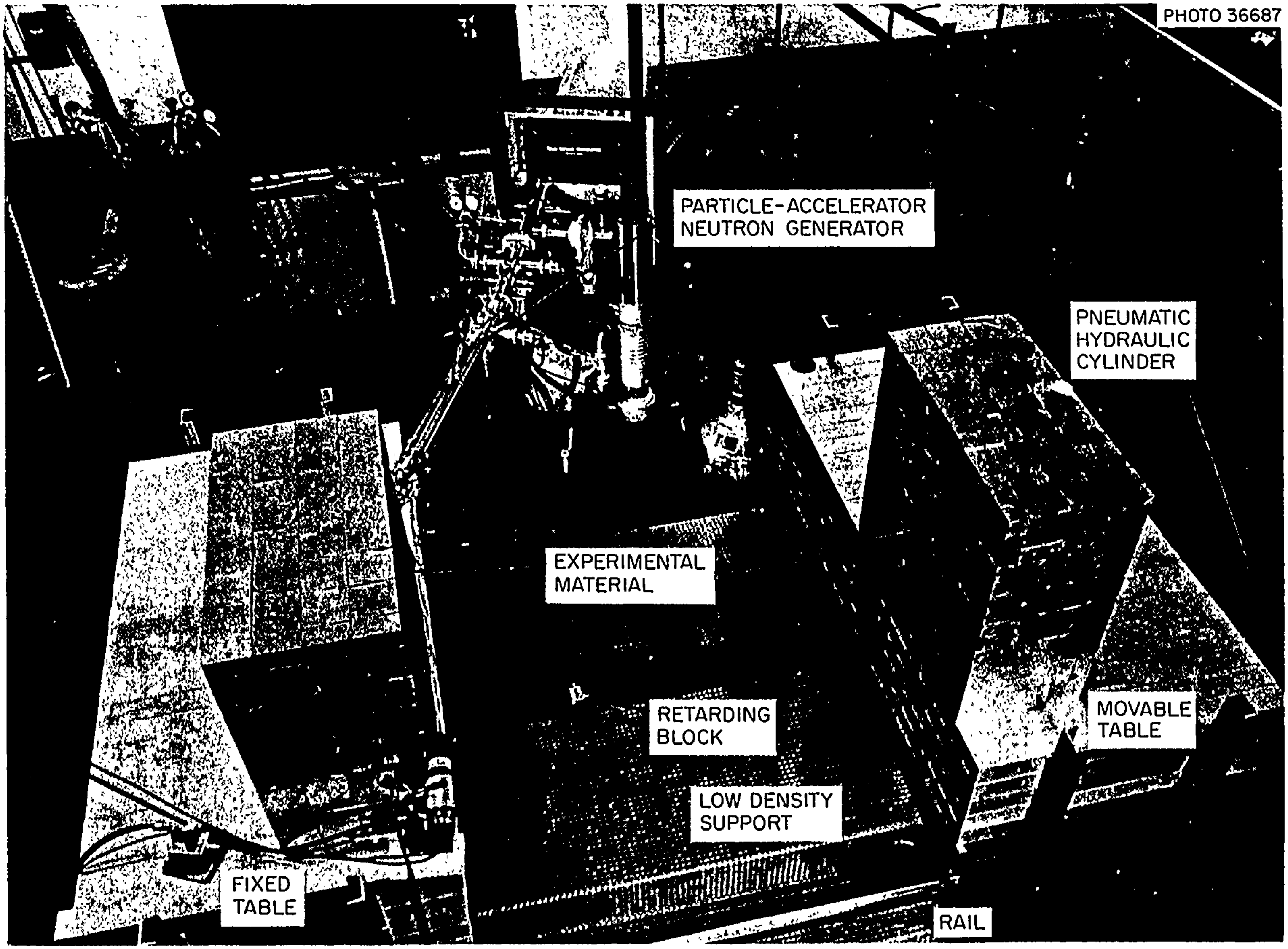


Fig. 10. Criticality Testing Unit, Horizontal Displacement.

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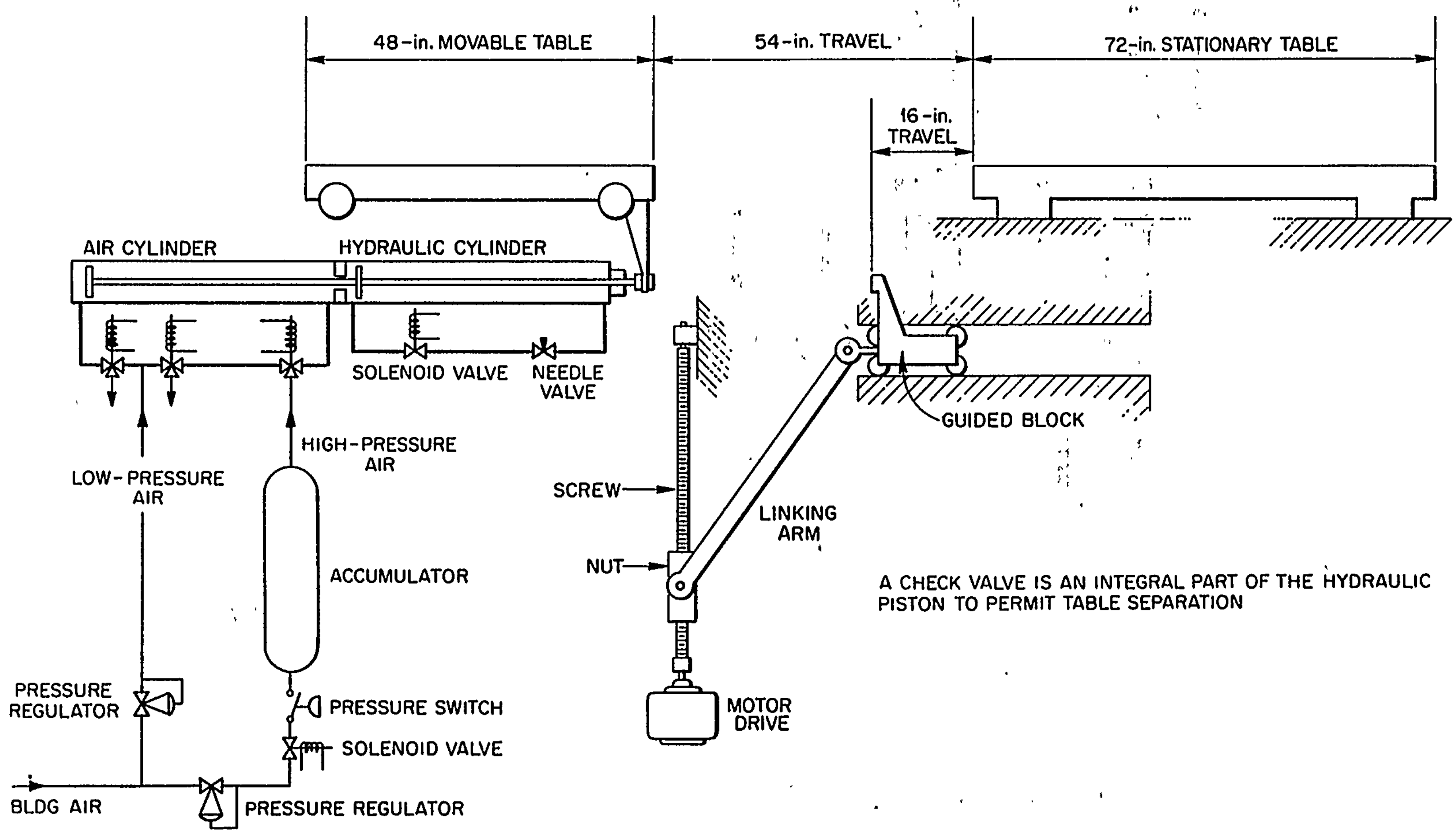

Fig. 11. Schematic of Criticality Testing Unit, Horizontal Displacement.

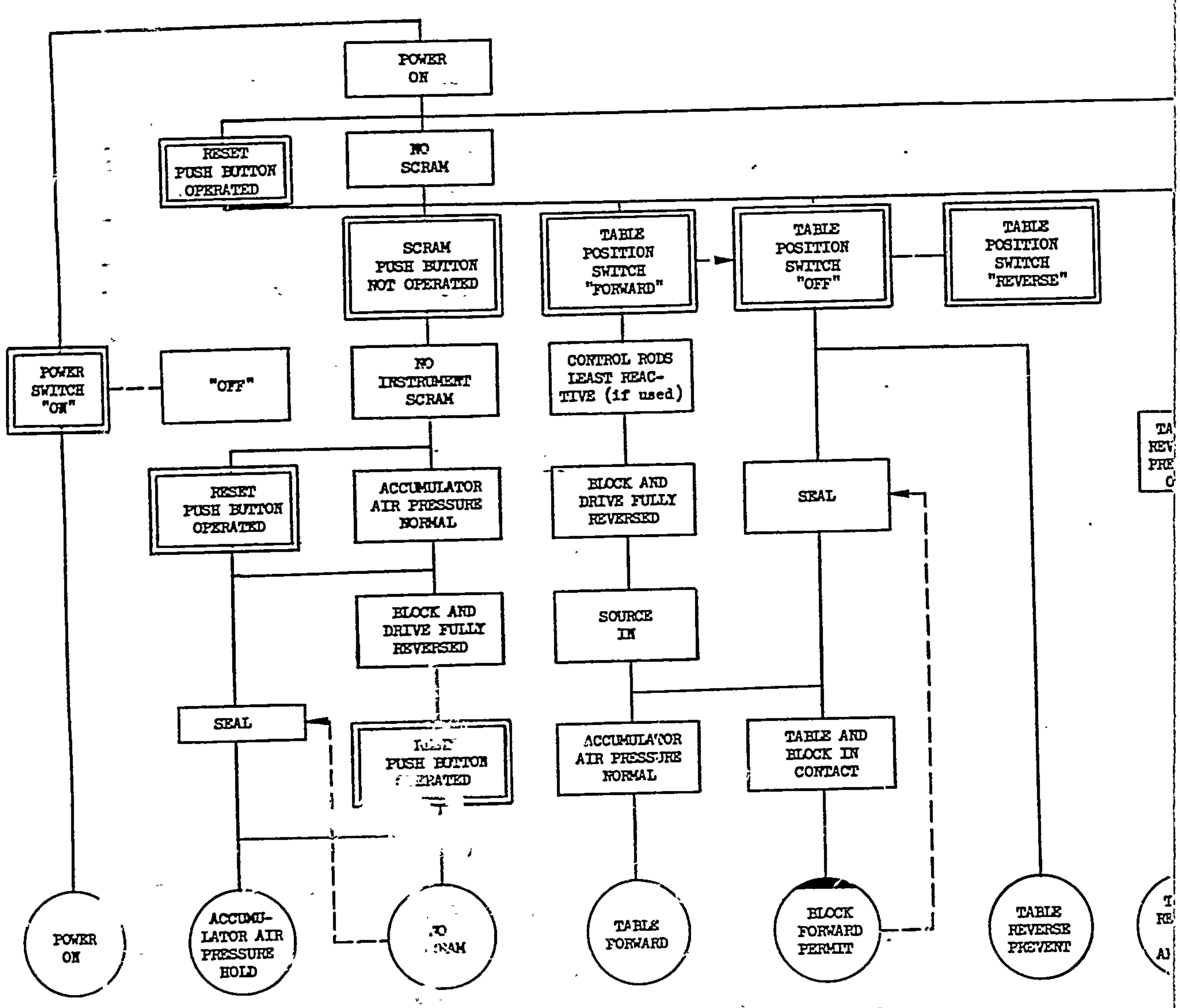

Fig.
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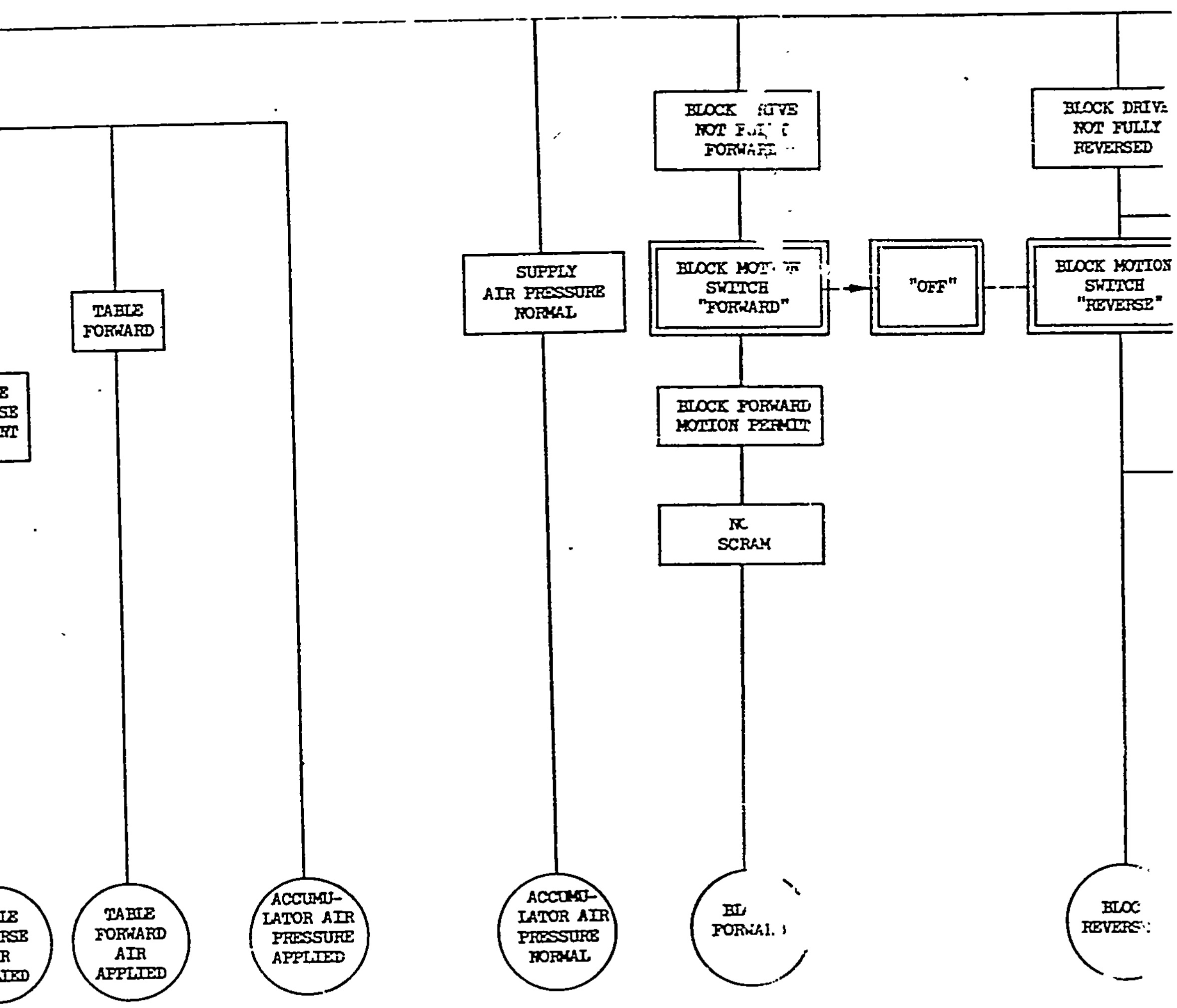

12. Control Block Diagram, Criticality Testing Unit, Horizontal
nt.

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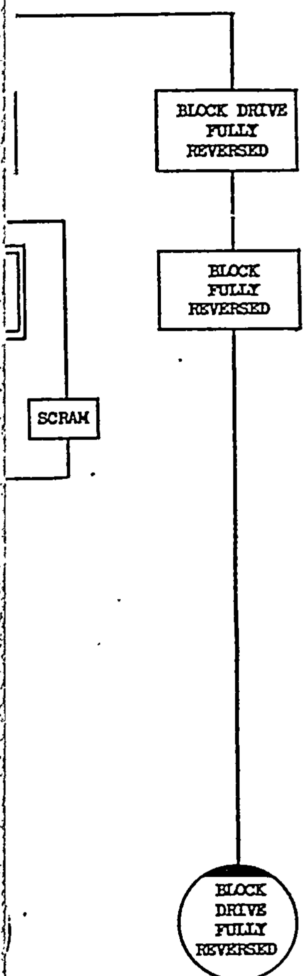
NOTE: Information flows only horizontally and downward along the information paths, never up toward the top of the sheet.



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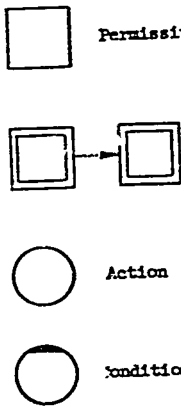

Permissive Condition

Manual Switch
Dashed interconnecting li
indica [illegible] positions of same
switch. Arrow shows direc
of spring return.

Action

Condition

travel. The piston of this cylinder is actuated by low-pressure air during normal motion. The table drive is designed so that the return motion, even in normal operation, is faster than the forward motion. High-pressure air, employed during emergency conditions, effects a much faster component separation.

The maximum rate of forward motion is established by manual adjustment, at the equipment, of the pressure of the low-pressure air supply and of the needle valve in the oil line connecting opposite sides of the hydraulic piston. The rate of advance over the final 16 in. of travel to closure is limited by a retarding block which is moved, in turn, at a continuously decreasing rate by a mechanism similar to that embodied in a scissor jack. The mechanism includes a screw and nut, driven by a constant-speed motor and mounted perpendicular to the direction of table travel. Translatory motion of the nut is transferred to the retarding block, guided in the direction of table travel, by a linking arm. The speed of the nut and its position on the screw determine the speed of the block.

The time for table closure is established by the pressure of the air supply, the settings of the needle valve in the hydraulic line, the manual control of a switch at the console operating both the valve feeding air to the cylinder and the solenoid value in the hydraulic line, and, over the final 16 in. of travel, by the motion of the retarding block. It is pointed out that closure of the solenoid valve terminates forward motion instantly.

A typical operation is described as follows. For a given needle valve setting the cylinder drives the table forward at about 0.6 in./sec when the air pressure is 25 psig. The table is moved forward at this fixed rate by the piston rod until it makes contact with the retarding block, at which time an interlock allows the motor to rotate the screw. The retarding block and the table, since they are in contact, move at a rate dependent on the location of the nut. The maximum speed of the block, 0.18 in./sec, occurs when the tables are separated 16 in. and the nut is farthest from the line of motion of the block. As the nut advances, the block speed decreases to 7×10^{-3} in./sec at table closure. About 7 min is required for this displacement. With this arrangement, the table is held constantly against the block during forward motion but is free to move back from the block and from the fixed table at any time.

A sketch of the drive arrangment, showing the scissor-jack mechanism and linkage, as well as the pneumatic-hydraulic system is included in Fig. 11.

The table separation may be brought about in three ways. One of these is the reversal of the direction of motion of the retarding block which, even though the forward-directed air pressure is applied, will separate the tables at the speed of approach described above. The second is application of the low-pressure air to the cylinder in such a way as to reverse the table motion; under these conditions the separation rate is about 4 in./sec at an operating pressure of 25 psig. When it is required to separate the tables quickly, high-pressure air from the accumulator is applied to the piston. A typical time rate of separation following an emergency signal, observed with a 315-lb load on the movable table, an 85-psig accumulator pressure and a 25-psig operating pressure, is shown in Fig. 13. Under these conditions the table moved 0.5 in. in about 240 msec and 7.7 in. in 1 sec. It is observed that about 100 msec elapsed before motion began.

The above time rates of linear displacement may be translated into time rates of reactivity change for particular experimental arrangements. In one case, an array of moderated, unreflected enriched uranium metal, the rate of change of reactivity with displacement at closure was observed to be 2.3 dollars/in., corresponding to a terminal rate of reactivity addition of 1.6 cents/sec. Measurements with several assemblies showed the spatial rate of reactivity change to be constant over the first inch or so of travel. On this basis, 1.4 dollars would be removed during the first quarter of a second and the order of 10 dollars during the first second of emergency shutdown action. It is pointed out again that these values are dependent upon the size and composition of the assembly under study. Recorded information, derived for the purpose of establishing operating characteristics of various assemblies of enriched uranium metal, includes values of the sensitivity ranging from 0.5 dollars/in. to 6.4 dollars/in., all at component separations in the vicinity of 0.2 in. There is not an obvious simple empirical correlation of the sensitivity and the assembly structure.

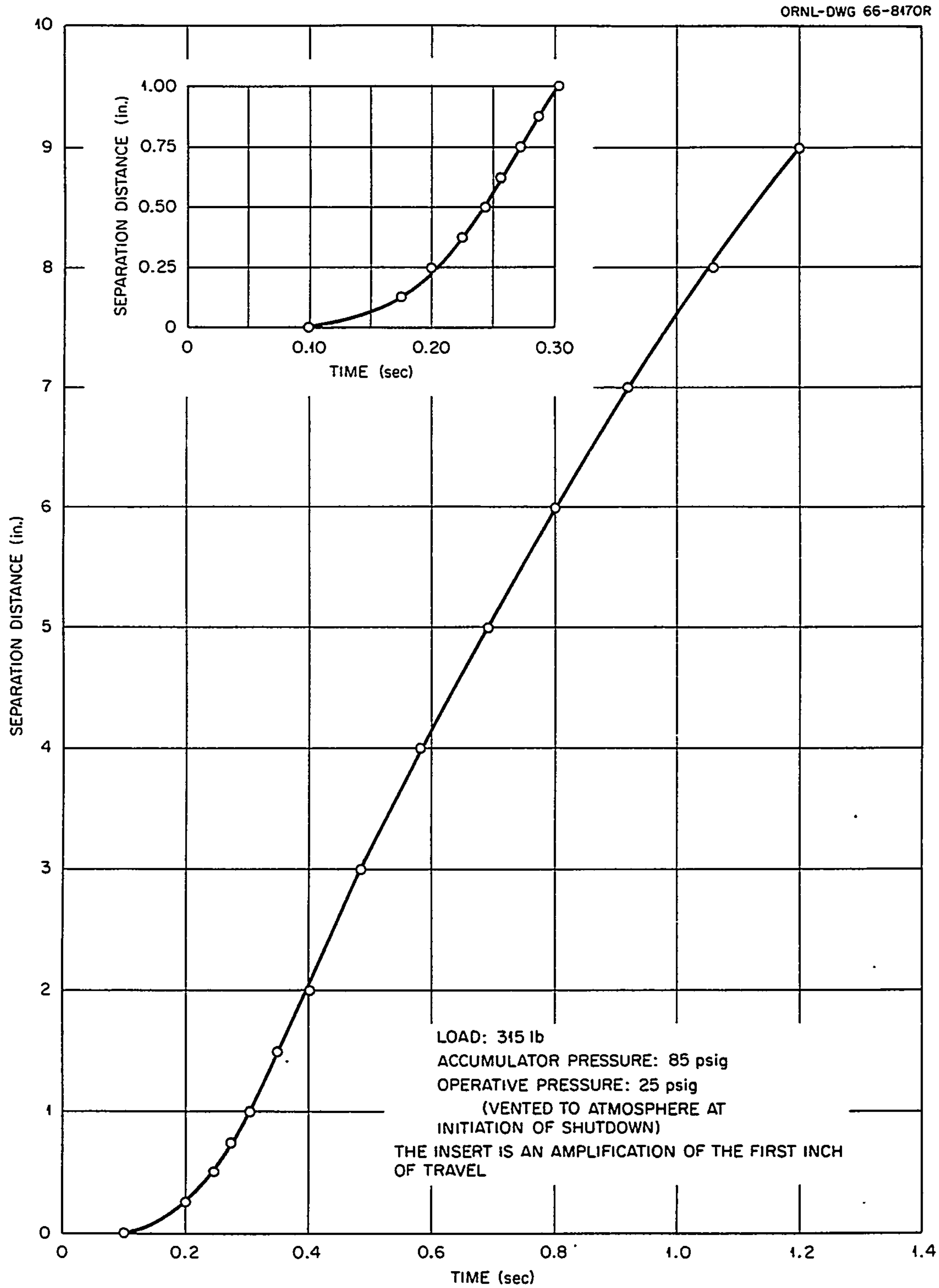

Fig. 13. Characteristic Emergency Performance of the Criticality Testing Unit, Horizontal Displacement.

As another example the observations from an experiment with an assembly of $U(3)F_4$ homogeneously mixed with paraffin are noted. The completed assembly was a 12-in.-high rectangular parallelepiped having a 32-in.-square base. The parallelepiped was constructed in two approximately equal sections. The reactivity as a function of separation of the sections was essentially linear over 0.6 in., the extent of the measurement, and amounted to 3.8 dollars/in.[c] With the linear speeds noted above, the terminal time rate of reactivity addition was 2.6 cents/sec and the initial normal shutdown rate, using the hydraulic system, was 15 dollars/sec. The emergency shutdown system removed 1.9 dollars in 240 msec following initiation of a radiation signal; it removed more than 20 dollars in 1 sec.

The loading and operating procedures for this equipment and the materials which may be utilized are the same as those appropriate to the Criticality Testing Unit for vertical displacement discussed on page 30. Experimental materials are mounted on these pieces of equipment in many ways, appropriate to particular experiments. The design criteria of the method of support which must be met are, first, sufficient sturdiness to prevent undesired motion of the components and, second, a minimum of material extraneous to the purpose of the experiment. In Fig. 10 is shown an assembly of closely fitting blocks, containing enriched uranium, for which only vertical support was required for stability. This support was provided by a stack of square aluminum tubing to minimize neutron reflection. In contrast, Fig. 14 shows uranium metal cylinders arranged in a three dimensional lattice requiring a separate support for each unit. In all cases the adequacy of the support is shown by structural analyses or by tests with inert materials.

<u>Criticality Testing Systems for Liquids</u>.

Critical experiments utilizing liquids are of two general types. In one a solution or a slurry of fissile material is transferred to a test

[c]In a much earlier experiment (Ref. 3) on different equipment and with different materials in an assembly whose components displayed facing areas 52 in. square the rate was measured as ~ 3 dollars/in.

3. E. L. Zimmerman, "A Graphite Moderated Critical Assembly CA-4," Y-881, Union Carbide Corporation Y-12 Plant Report (1952).

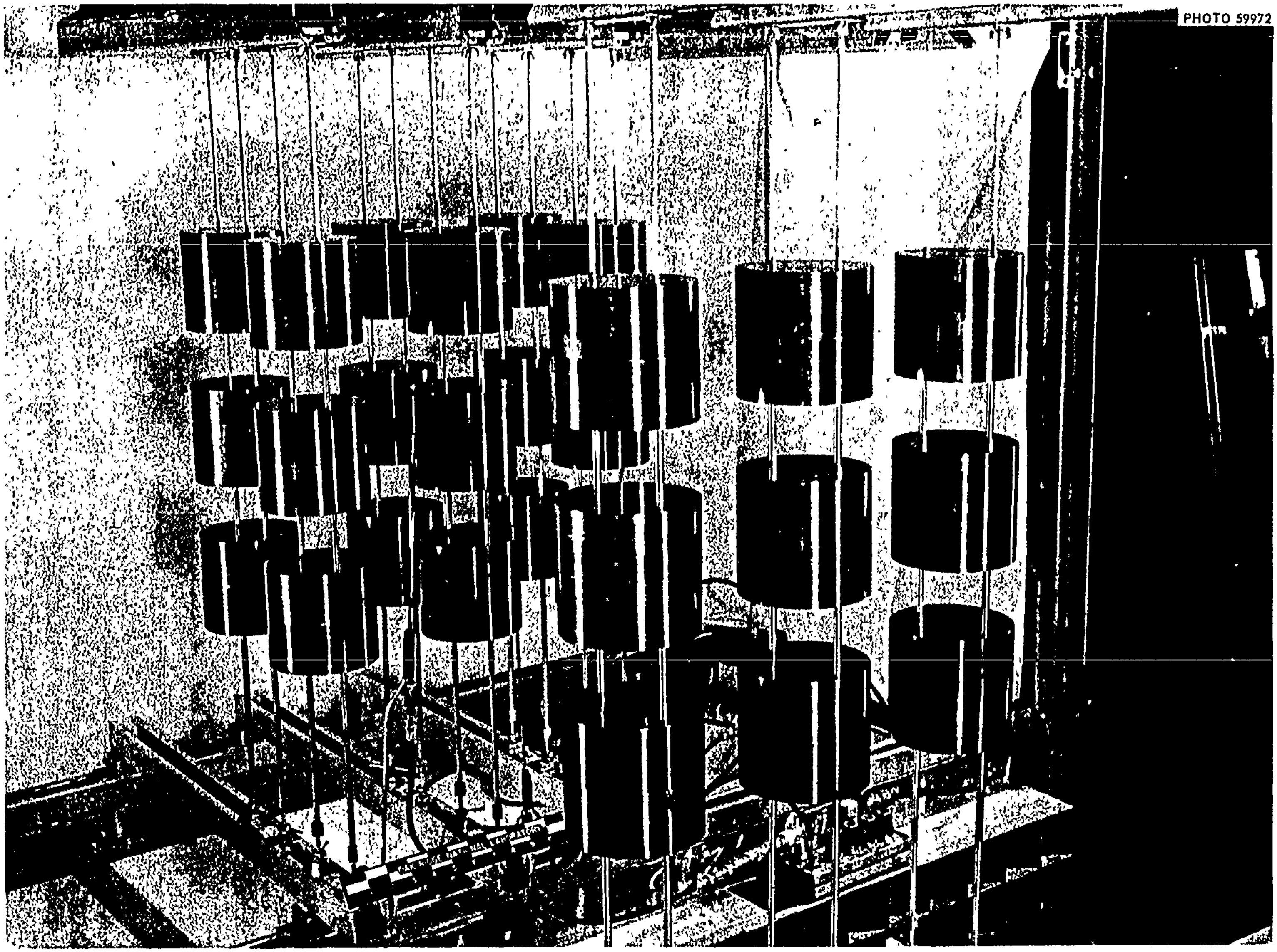

Fig. 14. Array of Fissile Units Showing Method of Support.

vessel. In the second type the fissile material, which may be either a solid or a contained liquid, is fixed in a vessel or tank to which a liquid neutron moderator and/or reflector is added. Criticality, of course, is achieved through remote operation of liquid-handling equipment in both cases. There are obvious combinations of these general types.

The most common aqueous solutions used in experiments of the first type are those of uranyl nitrate and uranyl fluoride. These naturally corrosive solutions must be used in systems which are protected in order to minimize the buildup of foreign materials. The time in storage far exceeds the time in use in a critical experiment; consequently, storage systems in particular must be constructed of corrosion-resistant materials. Permanently installed in the West Assembly Area of the Facility is such a system capable of remote operation after the necessary manual valve settings have been made. From time to time it is necessary to supplement this permanently installed system by other similar ones. Their description, too, is typified by the following.

Figure 15 is the schematic of an experimental system for uranium solutions, constructed entirely of polyvinylchloride, and Fig. 16 is the block diagram of its controls. The storage manifold consists of several 6-in.-ID cylinders ~ 20 ft long, slightly inclined to facilitate draining. Solution from these cylinders is pumped to a test vessel which is always located at a higher elevation than the storage system in order that solution may be returned by gravity. The system is vented at appropriate points through air filters. Referring to Fig. 15, A and D are remotely operable normally closed valves and B and C are remotely operable normally open valves. Valves A and B cannot be opened simultaneously. The other valves shown are manually operated and must be adjusted before an experiment is begun. The emergency "dump" system consists of a 10-ft length of 5-in.-diam pipe connected directly to the test vessel by valve C and short nipples. The minimum constriction in this line is 3 in. in diameter. A manually or instrument initiated emergency signal opens valves B and C, providing the maximum drain rate. Valves E, in a bypass, and F, which are not remotely adjustable, control the rate of solution flow through the 1/2 in. feed pipe. The maximum feed rate is such that it does not exceed the

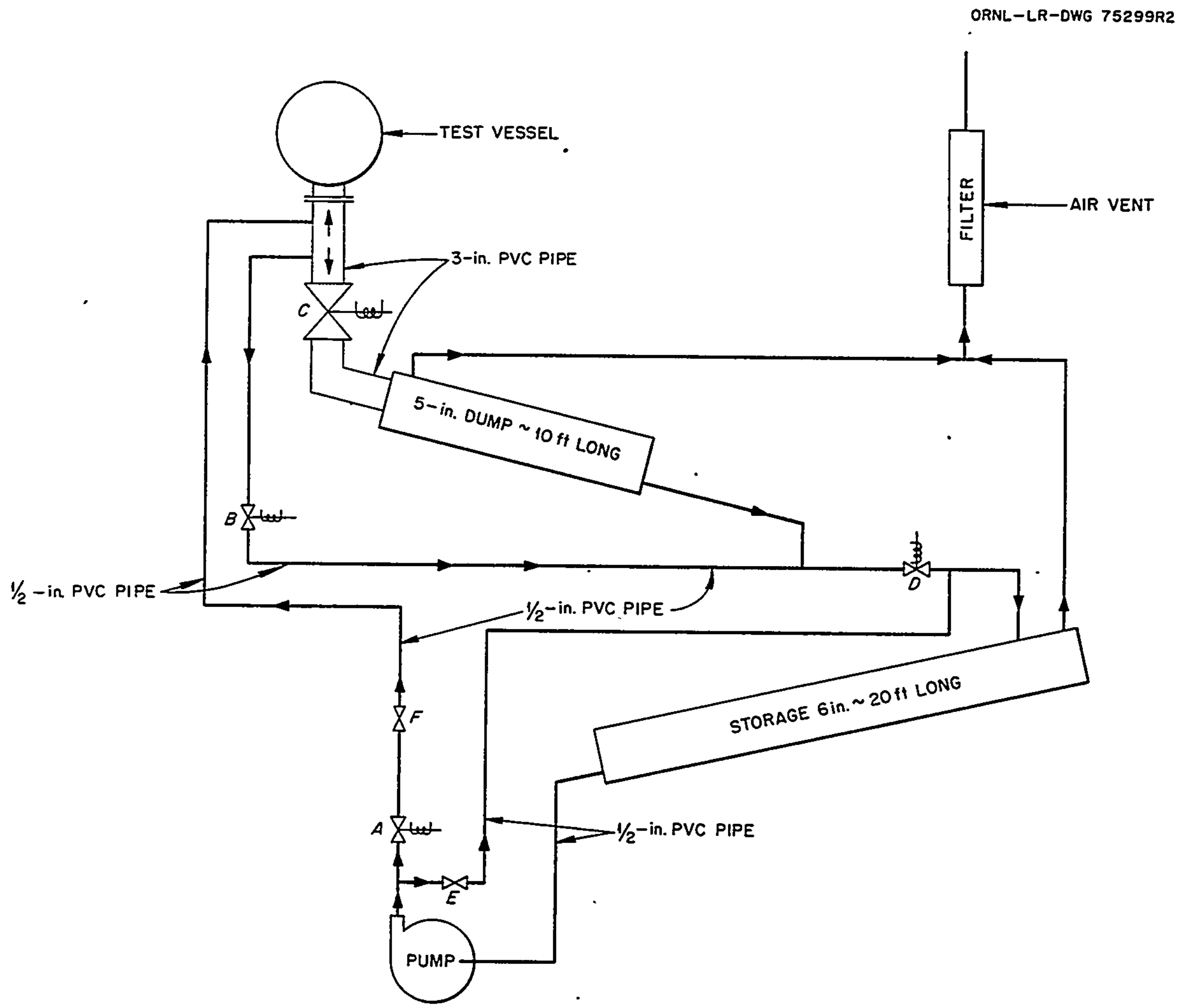

Fig. 15. Schematic of Criticality Testing System for Liquids.

NOTE: Information flows only horizontally a along the information paths, never u top of the sheet.

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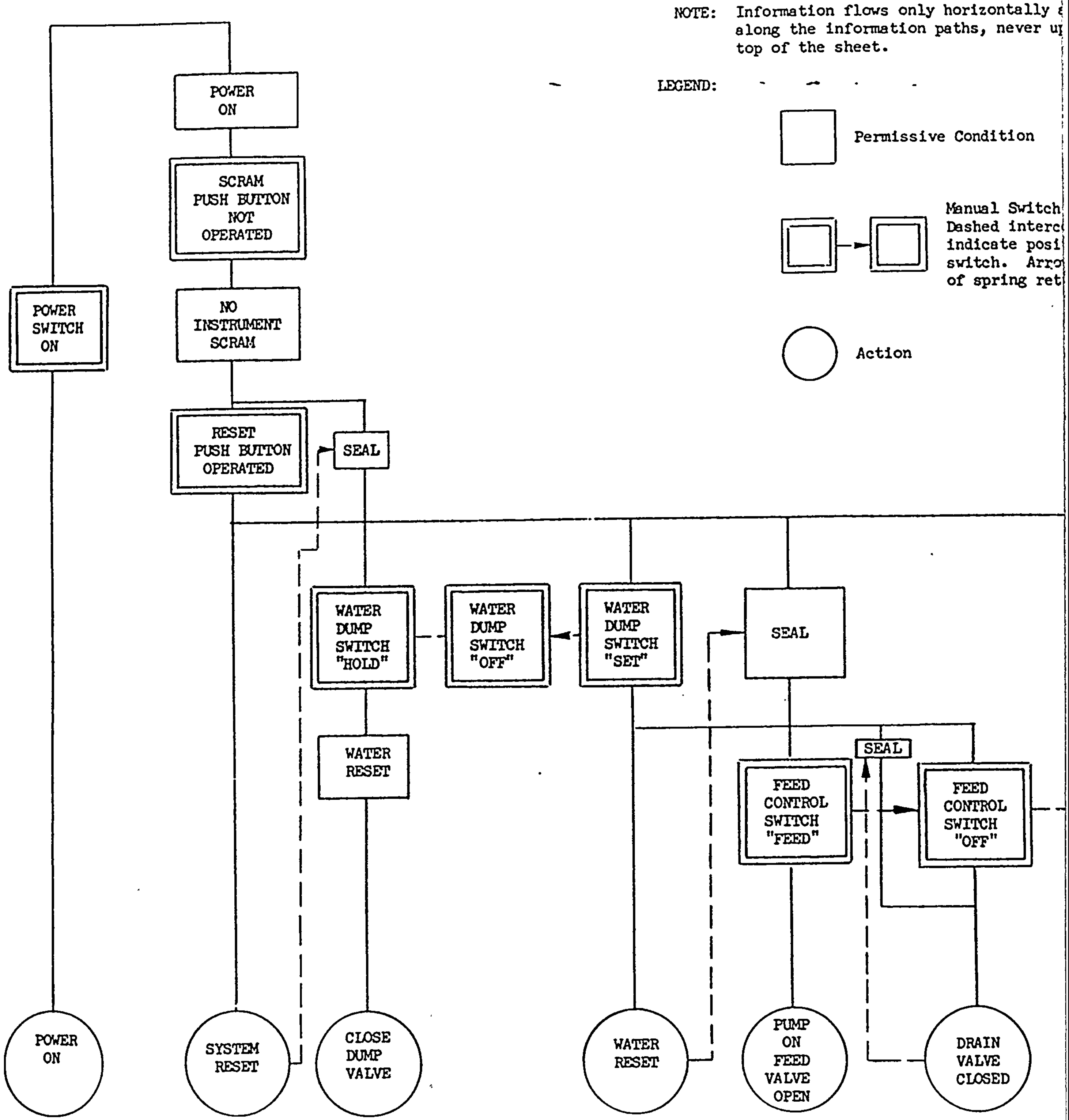

Fig. 16. Control Block Dia
Liquids.

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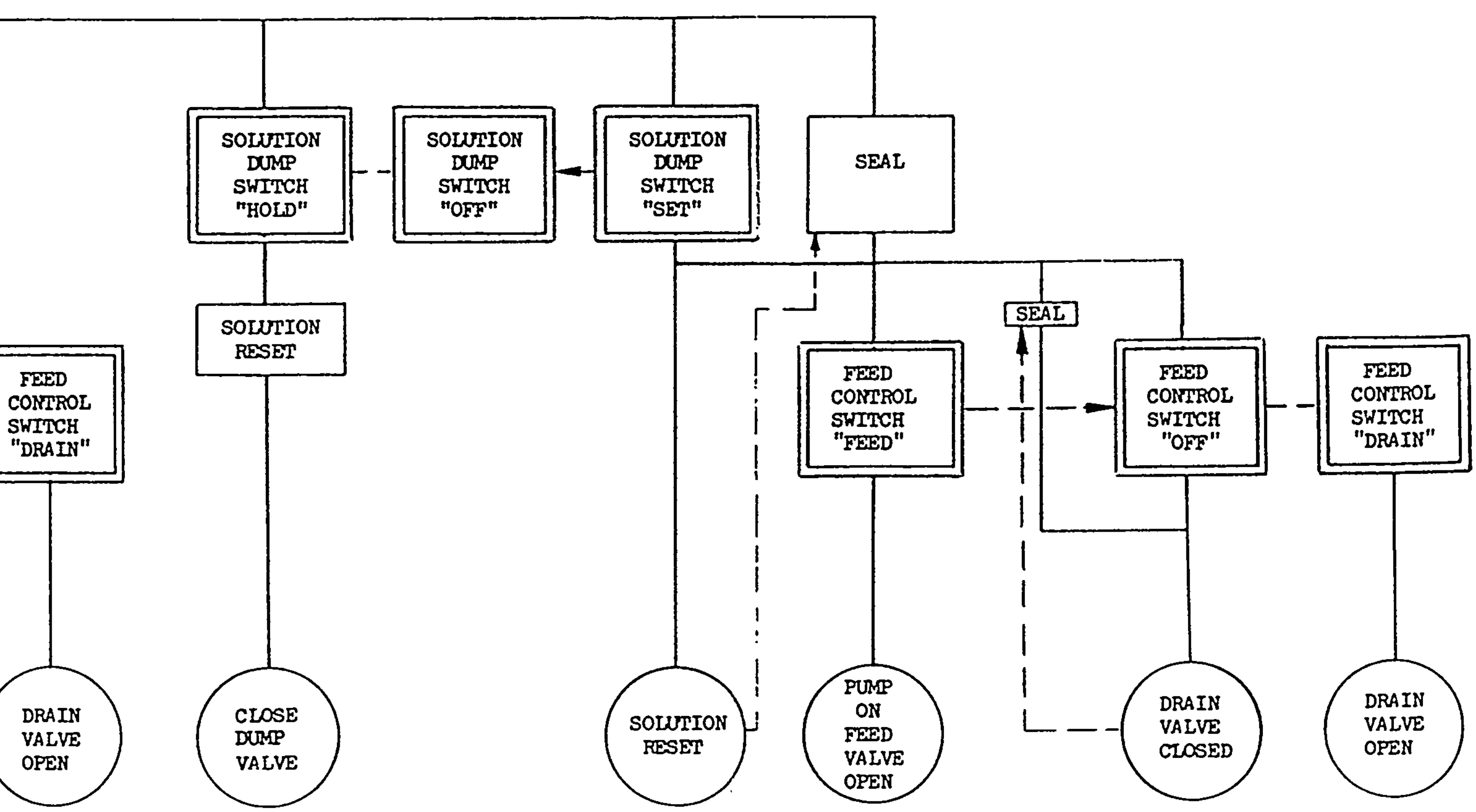


ram for Criticality Testing System for

drain rate through valve B and is much less than that through valve C. The acceptability of the feed rate of the solution is established, in the initial stages of addition, from timed increments of increase in elevation of liquid level. The liquid level is usually determined by a simple U-tube manometer located in the control room and connected directly to the liquid-feed line. In some experiments the level is located by an electrical contact probe with a selsyn readout.

The procedure for an approach to criticality is similar to that discussed for solid systems. Increments of solution as small as desired may be added to a test vessel by the manual adjustment of valves E and F and remote operation of A. Representative ratios of drain to feed rates are 5.6 for valve C and 2.5 for valve B for a fixed setting of valves E and F. As illustrative of the reactivity addition rates typically established, two examples are cited. The flow of $U(93)O_2F_2$ solution having a uranium concentration of 350 g/liter into a 10-in.-ID aluminum cylinder corresponded to a maximum rate of reactivity addition near criticality of 0.8 cents/sec; the corresponding rate of removal of reactivity was 4.5 cents/sec through the dump system and 2 cents/sec through the normal drain. In the second example, the critical dimensions of an array of 5-liter-capacity plastic cylindrical containers of $U(93)O_2(NO_3)_2$ were measured. The flow of solution was remotely controlled to the five central units of the array. The maximum rate of addition of reactivity was 7.3 cents/sec, with corresponding drain rates of 41 cents/sec through the dump system and 18 cents/sec through the normal drain.

Other means of reactivity control are available depending upon the experiment and its purpose. In each case, a suitable ratio of reactivity addition rate to removal rate is determined and evaluated prior to achieving criticality.

In addition to solutions of uranium salts, the materials for this type of equipment include slurries of insoluble uranium salts (continuously flowing or agitated), water, heavy water, and various organic solids and liquids.

In the second type of critical experiment utilizing liquids a quantity of fissile material, in solid form or as an appropriately contained liquid, is arranged by and in a manner so that a neutron moderator and/or reflector can be added by operations in a shielded area. The quantity initially assembled is established as being subcritical in the absence of the reflector and moderator by previous knowledge. Beyond this point the procedure is the same as the one with liquids alone described in the preceding paragraphs. A typical equipment arrangement is that shown in Fig. 15 without, of course, the limitations imposed on the dimensions of storage vessels and on connections by nuclear criticality safety considerations. In an example of this type of experiment rods of U(5) metal were arranged vertically in a pattern established by thin horizontal sheets of plastic in which holes were drilled. The assembly was made critical by the addition of water by remote operation. The water feed rate was adjusted so that, upon the approach to criticality, the time rate of increase in reactivity was 0.5 cents/sec. The corresponding rate of reactivity removal by the normal method was 3.9 cents/sec; by the emergency shutdown method it was 8.7 cents/sec.

Materials for use with this equipment include but are not limited to uranium in elemental, compound, and alloy form, solutions of uranium compounds, water, heavy water, organic liquids and various non-fissile solids.

Other Equipment.

The Facility has the capability of utilizing equipment for other experimental programs of short duration, thereby supplementing the more permanently installed apparatus already described.

Such an experimental program investigated the so-called Oak Ridge Health Physics Research Reactor (HPRR) prior to inauguration of its intended and purposeful use. The intent of this critical experiment was to explore the thermal, mechanical, and neutronic response of a mass of fissile material to the rapid addition of sufficient reactivity to exceed prompt criticality. The HPRR is described in detail in Ref. 4. It will suffice for

4. J. T. Mihalczo, "Super-Prompt Critical Behavior of an Unreflected, Unmoderated Uranium Molybdenum Alloy Assembly," Nucl. Sci. Eng. 16, 291 (July 1963).

this discussion to record that the critical assembly was a right circular cylinder of an alloy of U(93) and molybdenum equipped with four additional cylindrical pieces of alloy movable vertically through holes of appropriate size and location in the main cylinder. One of these, called the safety, was axially located and magnetically supported against gravity and a compressed spring. Its removal reduced reactivity ~ 20 dollars at an initial rate of one dollar during the first 38 msec after the shutdown signal. Another, called the burst rod, could be rapidly inserted from above by the action of a pneumatic piston, thereby adding reactivity in an amount up to 1.15 dollars depending upon its travel. The two remaining rods were continuously adjustable and could add, respectively, 1.95 dollars and 0.83 dollars in reactivity. The temperature coefficient of reactivity was measured as -0.31 cents/C^{o} over the range 20 to 135^{o}C. Delayed criticality was achieved, with the safety inserted and the burst rod withdrawn, by adjustment of the two remaining controls. With the assembly at delayed criticality, or removed from delayed criticality by a known amount, reactivity was quickly inserted with the burst rod.[d] In the progress of the experiment the maximum reactivity of the assembly, achieved by these insertions, increased from zero to somewhat above prompt criticality as required by the intent of the program. In all instances signals from radiation detectors and associated instrumentation, described in the following section, caused the safety to be ejected. In most cases the thermomechanical effects in the alloy and its attendant negative temperature coefficient reduced the reactivity below zero prior to action of the safety. In the production of the most intense pulses the safety was observed to be disengaged from its support by the shock wave, generated by the pulse, even before the signal from the detectors could be effective. The times of these actions following the peak of the pulse were about 200 μsec and 25 msec, respectively. In this manner pulses of energy of quite short duration were produced. The maximum energy resulted from a pulse of 1.8×10^{17} fissions produced by the

[d]Care was exercised, through sturdiness of structure and vigilant surveillance, to assure that reactivity was not altered between establishment of the desired conditions and insertion of the burst rod.

insertion of 11 cents above prompt criticality. The width of the pulse at half-height was 48 μsec and the maximum temperature rise was 400 C°. The integrated energy within 30 pulses produced in the stepwise approach to the maximum corresponded to that from the order of 10^{18} fissions.

It was from these experiments that the shield capabilities of the Facility, described later in this report, were directly evaluated.

VI. INSTRUMENTATION

Because of the diversity of operations at this Facility, instrumentation requirements vary and each assembly area is provided with some duplication of electronic equipment to permit the conduct of experiments covering wide power ranges by providing overlapping sensitivities among several channels and to minimize shutdown time caused by instrument maintenance. Most experiments are conducted at powers of less than 10 mW, although some routine measurements may be carried up to the order of 1 W. Extraordinary situations sometimes arise involving the order of 100 W, and occasionally controlled pulses of radiation are generated at a peak power of 10^5 MW. The numerous instrument channels, having different sensitivities and ranges of operation, are capable of providing adequate monitoring under all operating conditions.

A typical instrumentation system includes one logarithmic channel, two linear safety channels, one dual-output scintillation detector safety channel, one high level scintillation detector safety channel, and a radiation monitor alarm to signal building evacuation. At least two safety channels and the radiation monitor shall be operative throughout an experiment. A block diagram of typical instrumentation is shown in Fig. 17 and the components are described below. It will be observed that each instrument channel is independent of and isolated from all other instrument channels.

Logarithmic Channel. This channel provides visual indication of the neutron flux with a single range covering six decades. The integrated current from an uncompensated BF_3-filled ion chamber is fed to a logarithmic diode and the amplifier which follows develops an output which is proportional to the logarithm of the neutron flux. The output is displayed

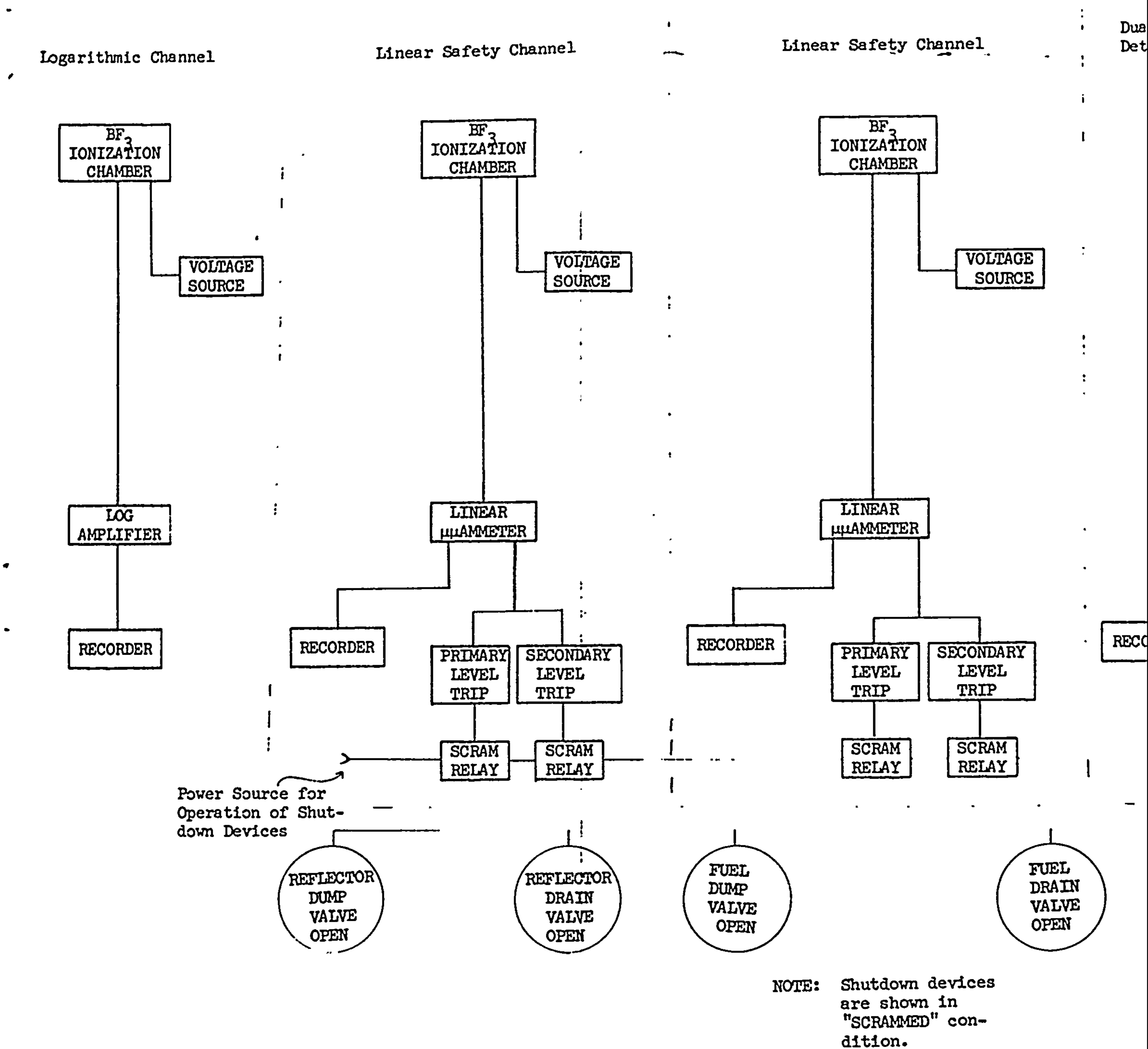
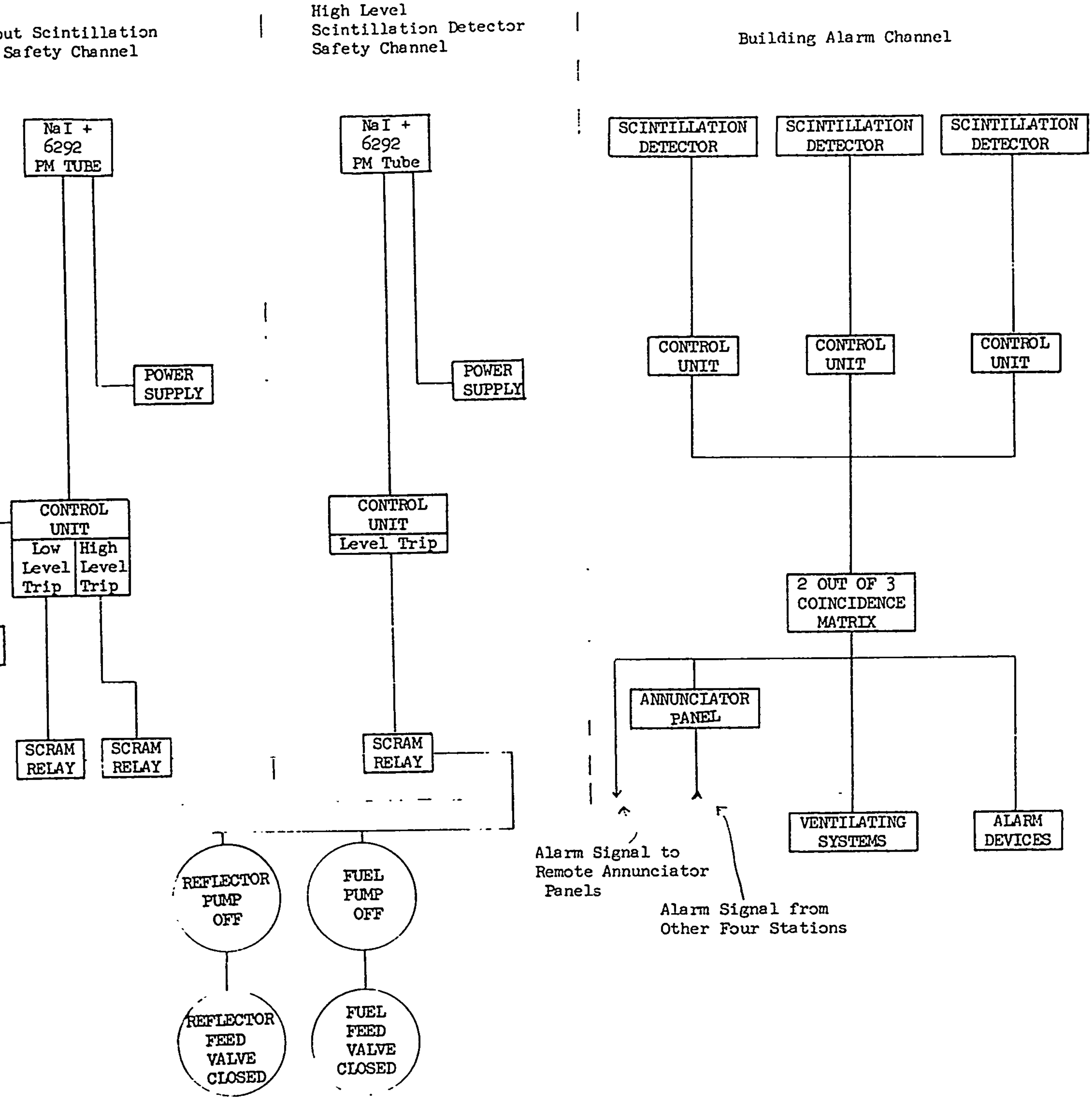


Fig. 17. Block Diagram of Typ
Testing System for Liquids.

ORNL-DWG 66-8928



...l Instrumentation for Criticality

on a panel meter and on a strip-chart recorder. Although this channel has no output to initiate any form of shutdown, it is included in typical instrumentation because it is capable of monitoring practically all experiments from start-up to the planned operating power without changing sensitivity.

Linear Safety Channel. Each of the two linear safety channels provides both a visual indication of the neutron flux throughout an experiment and a voltage signal to two level-trip circuits to operate two scram relays. In a typical channel, integrated current from an uncompensated BF_3-filled ion chamber is fed to a linear micro-microammeter in which the signal is amplified for display on a panel meter and on a strip-chart recorder. Full-scale range of the readout devices is adjustable in steps by a range selector switch. The output voltage of the instrument is proportional to the meter reading. This voltage feeds the two trip circuits to provide two modes of operation of the scram relays. The primary trip circuit consists of a vacuum tube with a current-sensitive plate relay. The output voltage increases in proportion to the neutron flux until, at a preset value, the relay is de-energized and a shutdown condition is established at the scram relay. This value is about 150% of the signal required to give a full-scale deflection of the output meter for that particular instrument range. This trip point may be confirmed by reducing the instrument sensitivity one step and noting the signal level. By this means a shorter interval exists between operating and shutdown voltages than would for a circuit requiring a fixed shutdown signal. Loss of power to this circuit, loss of gain in the tube, and an open coil in the relay result in a shutdown condition. To this extent the circuit is fail-safe.

The secondary trip circuit consists of a contact meter-relay and a sensitive auxiliary dc relay. Sensitivity of the contact meter is adjusted so that a signal from the micro-microammeter corresponding to about 115% full-scale deflection of its panel meter closes the contact. When the contact is closed the auxiliary relay is energized and a shutdown condition is established. The response of this circuit to the rapid changes typical of radiation incidents is slower than that of the primary circuit. The secondary circuit provides an additional shutdown signal to the series scram relay string as a backup to the primary circuit.

Scintillation Safety Channel. The dual-output scintillation detector safety channel, generally insensitive to start-up signal but responsive to assembly power greater than about 1 mW, provides both visual indication of the gamma-ray intensity and on-off signals to the dual-level trip circuit to initiate emergency shutdown. A typical detector consists of a sodium iodide scintillator mounted on the face of a ten-stage multiplier phototube. The integrated output signal, proportional to the gamma-ray intensity, is introduced into the control unit which provides visual indication on an output meter and on a strip-chart recorder, and transmits the signal to the trip circuits. Each circuit operates on the same principle as the primary trip circuit in the linear safety channel and has similar fail-safe characteristics. The values of the trip signals are preset such that the lower one operates a scram relay at a power slightly greater than the anticipated operating limit and the upper one operates a scram relay at a power about two orders of magnitude higher.

The high level scintillation detector safety channel is similar to that described immediately above. It differs in that a single preset trip signal several orders of magnitude above the operating limit actuates a scram relay. This relay is connected in the series scram string as a backup to the other channels.

When a trip occurs in any channel, the scram relay in that channel interrupts the power to the shutdown devices and illuminates a red warning light indicating that the instrument has tripped. The contacts of all safety-channel scram relays are connected in series so that a single instrument trip will produce a scram.

The response time of a safety channel, i.e., the time required for a step-function impressed on the input of an instrument channel to deenergize the shutdown devices, is the order of 10 msec. For most types of experiments this is adequate, being commensurate with the time behavior of the mechanical and electromagnetic components of the shutdown devices themselves.

Fast Safety Channel. The fast safety channel, designed for use with experiments in which rapid response is of greater than usual importance, is similar to the dual-output scintillation detector safety channel described earlier. Its response time, about 0.5 msec, is obtained by feeding an amplified photomultiplier output signal directly to the controlling circuit of a specially designed magnet power supply. This power supply provides full magnet current from a vacuum tube circuit. When the controlling voltage of the power supply reaches the preset trip point, the magnet current is cut off by an electronic switch. In addition, this channel includes a relay-operated trip circuit having a response time of about 10 msec.

Shutdown Devices. Although shutdown devices are more fully included in the earlier descriptions of specific apparatus, it is appropriate to associate them here with the instrumentation signaling an emergency.

Power to the shutdown devices is cut off when any one of the several scram relay contacts in the series string opens. The type and number of shutdown devices are determined by the nature of the experiment. A typical experiment with liquids includes dump and drain valves which open to allow fissile solutions or reflector and moderator liquids to flow from the assembly. As an added safety, prevention of addition of reactivity is accomplished by de-energizing the pump and closing the feed valve. The components of solid assemblies may be separated by gravity or by the action of fluids under high pressure following removal of power from magnets and valves. Shutdown devices are fail-safe to the extent that, on loss of electrical power or loss of air pressure, their action tends toward the desired mode. For example, valves controlling the addition of fissile solution to an assembly fail closed; those permitting the solution to drain from the assembly fail open.

Building Alarm. The building alarm is a single system of horns, bells, and sirens situated throughout the Facility area which serve, when actuated, as warning to personnel that an accidental radiation excursion has occurred. The radiation monitors which provide the signal to the system are scintillation sensors located, in groups of three, in each of five sensitive areas within the building where fissile material is stored and handled. The alarm is automatically sounded when the radiation at two of the three monitors constituting a group reaches a preset value. The location of the monitors initiating an alarm is identified as a room number by the illumination of the appropriate block on each of five annunciator panels. The initiation of an alarm stops all air-moving equipment in the building, turns on the flashing red light on the roadway from the main Y-12 Area (warning traffic not to proceed onto the road which passes the Facility), and indicates in the office of the Y-12 Plant Shift Superintendent.

VII. LIMITATIONS ON EXPERIMENTS

As has been stated previously, the versatility of the Facility has been demonstrated by the successful performance of experiments with fissile isotopes of uranium in almost every conceivable configuration with and without other materials of interest. It has also been pointed out that a more complete evaluation of contamination potentials will be made if large quantities of materials more toxic than uranium are used. Experience in other laboratories and production centers has shown that containment can be successfully effected in reasonably simple and inexpensive ways.

There have been occasions in the past, and there probably will be others in the future, when, in the judgement of operating personnel, it was not expedient to achieve criticality. These decisions have been governed by the nature of the material, by expected consequences of an incident, and by deficiencies in the experimental equipment. Limitations on experiments or experiment programs at the Facility may arise from evaluation of the risks associated with a particular operation. In most cases, of course, assemblies are made critical in order to unequivocally establish the desired information.

VIII. MANUAL OPERATIONS WITH FISSILE MATERIALS

Manual operations with fissile materials, including storage, transportation, and the initial steps in critical experimentation, are governed by accepted practices. These practices are based on published recommendations[5] or the results of relevant experiments. The operations are reviewed and approved internally by the ORNL Criticality Committee as a part of the Laboratory's safety program mentioned below.

IX. FACILITY ORGANIZATION AND STAFF

The Critical Experiments Facility is organized as a part of the Neutron Physics Division of the Oak Ridge National Laboratory, the responsibility for the operation of the Facility being vested in a supervisor. This responsibility derives from the line organization established within the Laboratory for the administration of all supervisory functions including safety. For guidance in matters of safety the Neutron Physics Division has established a Safety Review Committee, which reviews the unique safety aspects of the experimental activities within the Division. The Committee consists of the Division Director, the supervisors of the various facilities operated within the Division, and other experienced technical personnel.

The safety organization of the Oak Ridge National Laboratory includes a number of committees who advise the Director of the Laboratory on all manner of safety. Among these is the Criticality Committee to which is assigned the responsibility for the safety review of this Facility with respect to both the performance of critical experiments and all other opertions with fissile materials. The Committee makes at least one review annually and remains available for consultation and action at all other times. It is kept informed of activities of the Division Safety Review Committee.

The Facility is staffed by technically qualified individuals. At the time of this writing (February 1967) the technical staff comprises 11

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5. USASI Standard N6.1-1964, Safety Standard for Operations with Fissionable Materials Outside Reactors (1964); Nuclear Safety Guide, AEC Report TID-7016, Rev. 1 (1961).

scientists and engineers, four technicians, and a part-time health physicist to some of whom is delegated the responsibility for the experimental programs.

By academic training the 11 technical persons may be classed as six with Ph.D. degrees (or equivalent), four with master's degrees (or equivalent), and one with a bachelor's degree. Of the four technicians, two have college training, not necessarily, however, in technical fields. Six scientists qualify as senior experimenters, defined in the Operating Limits, Section II, and four members of the staff as experimenters. On the average, the members of the groups have had 11 and 9 years experience in critical experiment operation, respectively. These statistics are significant because they indicate the background and the caliber of the persons to whom the operations are assigned. This invaluable experience is an important adjunct to any amount of formal academic training.

Additional personnel include two secretaries, a janitor, a security guard located adjacent to the Facility during regularly scheduled hours, and personnel from maintenance and other supporting services assigned to the Facility from time to time as need demands. In this manner the number of personnel regularly within the area is minimized.

X. PROGRAM IMPLEMENTATION

The need for and desirability of a particular experiment program at the Facility is first established at the Division level after, in many cases, consultation with others from both ORNL and outside groups to whom the information to be derived will be useful. If, in the judgement of the Facility Staff, the program is significantly different from others which have been performed at the Facility, the proposed program is reviewed in detail by the Division's Safety Review Committee. The Safety and Radiation Control Department of the Laboratory is kept generally informed on all programs in progress at the Facility, particularly on those reviewed by the Division Committee. For further independent review of the safety aspects of a program, the Department can refer it to the Laboratory Director's Criticality Committee.

The responsibility for organizing and carrying out each program is assigned by the supervisor of the Facility to one of the senior experimenters. He, in collaboration with the supervisor, other members of the staff, and outside specialists, develops the details of materials, equipment, instrumentation, and procedures required for the program.

After agreement on the experimental materials and methods, operations follow generally accepted procedures, modified and amended if necessary to conform to the demands and unique features of the particular program in question. Necessary changes arising during the program are developed in consultation among senior experimenters. Changes of sufficient importance are reviewed as required by the Division Committee, by the Safety and Radiation Control Department, and by the Criticality Committee.

Normal and emergency practices having safety requirements and significance within the Facility are governed by Operating Limits and an Emergency Plan constituting Section II and the Appendix, respectively.

XI. RADIATION INCIDENT EXPERIENCE

The potential radiation risks, defined as accident probabilities weighted by their consequences, attendant to the activities in the Facility may be classed as those associated with normal operations and those resulting from some malfunction of equipment or personnel. In the former may be, for example, exposures to neutrons and gamma rays used regularly for various necessary operations, exposures to delayed-fission-product and natural radiation from experimental materials, and exposure to the prompt radiation generated in nuclear chain reactions. Knowledge of and adherence to prescribed shielding, provided both by distance and by appropriate materials, will limit exposures to members of the Facility Staff and to the public to within bounds specified in AEC Manual 0524 and in National Bureau of Standards Handbook 69.

Of much greater importance are the risks associated with unusual operations and occurrences. Among these are contamination and exposure resulting from the dispersal of natural (Po, ^{234}U) and artificial (^{233}U, Pu, fission products) radioactive materials. There is also the possibility of exposure to prompt and delayed radiation arising in fissions occurring in chain reactions of greater intensity than scheduled. The principal concern in this discussion is with the conditions generated in these unplanned occurrences.

Any discussion of the expected magnitude and consequences of incidents, be they nuclear or otherwise, is highly speculative because of uncertainties in the assumed cause of the incident and in its progress. It is possible, however, to support considerations of the consequences of possible accidental occurrences in this Facility by reference to recorded criticality incidents. In addition, radiation from extended operations of critical assemblies at relatively high power and from purposely generated intense radiation pulses of short duration, characteristic of those expected from incidents in certain critical experiments, provide valuable information for criticality incident evaluation. This discussion of potential risks is, perhaps, made unique by these pertinent experiences.

Throughout the following discussion of risk potential at the Facility it should be recognized that the staff is augmented by a member of the ORNL Applied Health Physics Group who is capable in specialized techniques of radiation detection and protection. The services for which health physicists are responsible are delineated by ORNL management.[6] The satisfactory manner in which these responsibilities are implemented reduces significantly the possibility of exposures to personnel.

Experiences with Radiation Incidents.

The most severe incident in the history of the Facility occurred in the spring of 1951 and is reported by Callihan and Ross.[7] It was caused, basically, by security-imposed restrictions on communications between the fabricator and the user of a polonium-beryllium neutron source. Misinterpretation by the fabricator of the specifications resulted in a capsule of

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6. "Procedures and Practices for Radiation Protection," Oak Ridge National Laboratory (1965).

7. D. Callihan and D. Ross, "A Review of a Polonium Contamination Problem," ORNL-1381 (Aug. 12, 1952).

extremely impractical design of which the user was not made aware and was not able to observe by inspection at the necessary safe-exposure distance. The capsule, containing about 7 curies of polonium at the time of the incident, became opened, causing wide dispersal of the polonium throughout one of the assembly areas and significant internal and external contamination of an employee. Medical and clinical findings indicated no detectable personal damage was incurred from the radioactivity. The quantity of beryllium associated with the inhaled polonium was too small to be toxic. Many small items were disposed by burial; others, including the cell itself, were decontaminated in a long and laborious process.

Next in order of severity are noted several instances of contamination principally by ^{233}U and ^{234}U, resulting from dispersal of aqueous solutions of enriched uranium through the failure of welded joints and the rupture of vessels. In some of these, personnel have experienced an intake of significant but permissible body burdens of uranium. Many entailed arduous labor for decontamination of plant, personnel, and equipment.

Three supercritical quantities of ^{235}U-enriched uranium have been unintentionally assembled. Two of these incidents, reported by Thomas and Callihan,[8] involved aqueous solutions. In the first of these two, which occurred in May 1954, a reactivity addition of 2.8 dollars to a volume of solution generated 0.9×10^{17} fissions; in the second, in February 1956, the yield was measured to be 1.6×10^{17} fissions but the reactivity addition is not known. Although both solutions were in open vessels, in only one was any liquid expelled. In both cases the safety devices operated within a few hundred milliseconds, and the systems were returned to below delayed critical in the order of a second. The power-time patterns probably consisted of an initial spike terminated by temperature and gas-evolution effects followed by an essentially constant-power interval during which the solution was near delayed critical, until the safety devices became effective. The total personnel exposure to neutrons and gamma rays incurred in the second of the above incidents are recorded in Fig. 18. Exposures in the

8. J. T. Thomas and D. Callihan, "Radiation Excursions at the ORNL Critical Experiments Laboratory," ORNL-2452 (May 5, 1958).

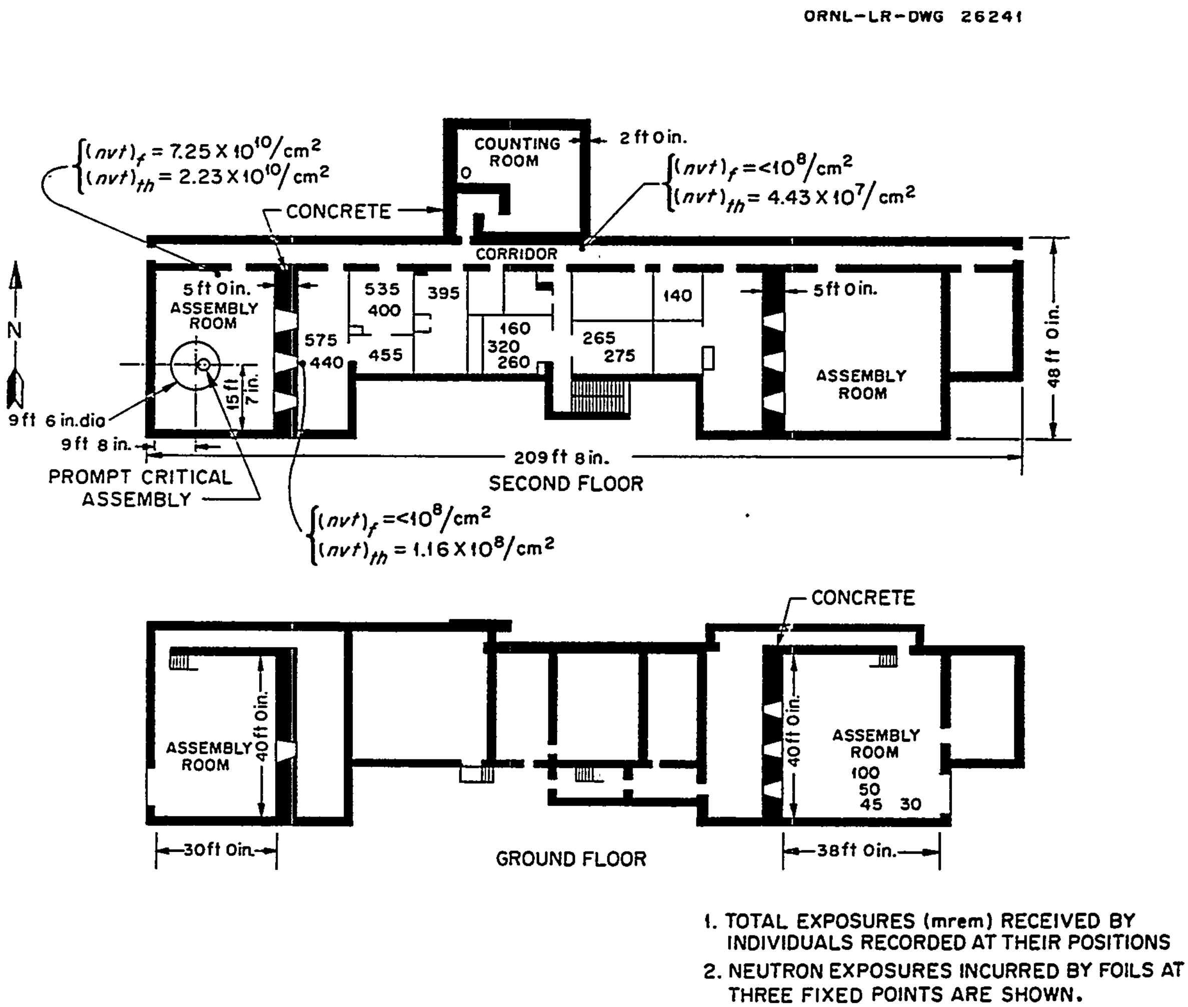

Fig. 18. Radiation Exposures from February 1956 Incident.

first incident were comparable. It is pointed out that since the occurrence of these two incidents both the heavy shielding on the south side of the building and the additional roof shielding described earlier were added to the Facility.

The third criticality incident, reported by Callihan,[9] occurred in November 1961 as ^{235}U-enriched uranium, neutron-moderated and -reflected by hydrogen, was being assembled. The yield was estimated to be 10^{15} to 10^{16} fissions. There was no exposure to occupants of the building or dispersal of airborne activity beyond the assembly area in which the incident occurred.

Controlled Radiation Experience

Measurements have been made at a number of locations throughout the Facility area of both the intensity of the radiation field and the integrated exposure resulting from extended operations of critical assemblies at relatively high power. Typical results are presented here.

A volume of solution, located in the West Assembly Area, was operated in January 1960 at an average power of 7×10^{12} fissions/sec, yielding a total of 3.7×10^{16} fissions. The purpose of the experiment was to provide radiation for dosimetric studies close to the source. Additional dosimeter measurements, of interest to this discussion, were made at a number of points outside the assembly area and are recorded on Fig. 19. The gamma-ray and neutron intensities were measured by portable survey meters[e] and the exposures were determined by film.

The measures given in Fig. 19 were made after the shield additions described previously had been completed. An interesting comparison of these data with those from an identical experiment (not reported here) prior to the addition of the extra roof shield shows that whereas exposures within the building were reduced, many at locations outside the building were actually greater with the increased shielding present. This increase is attributed to radiation scattered by the more massive roof.

[e]Appreciation is expressed to L. C Johnson and R. D. Parten of the ORNL Health Physics Division for these data.

9. D. Callihan, "Criticality Excursion of November 10, 1961," ORNL-TM-139 (Feb. 13, 1962).

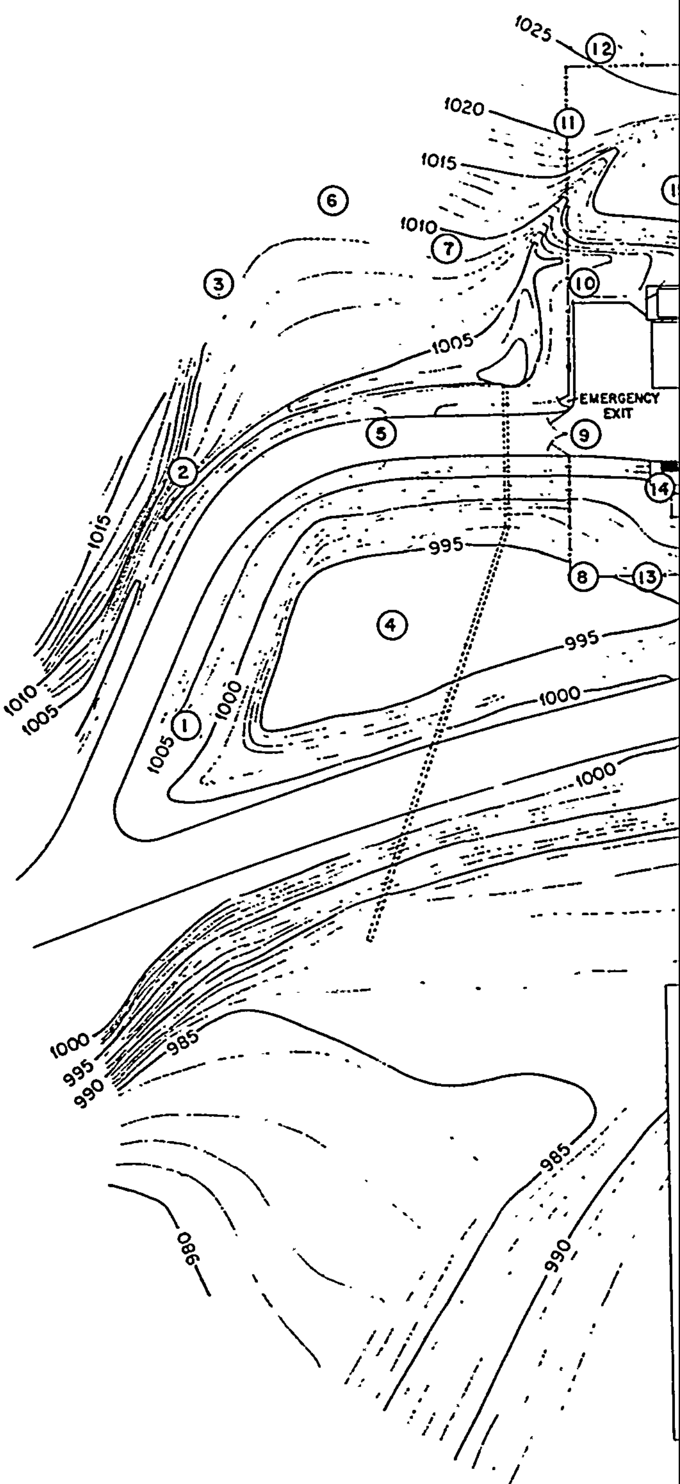
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Fig.

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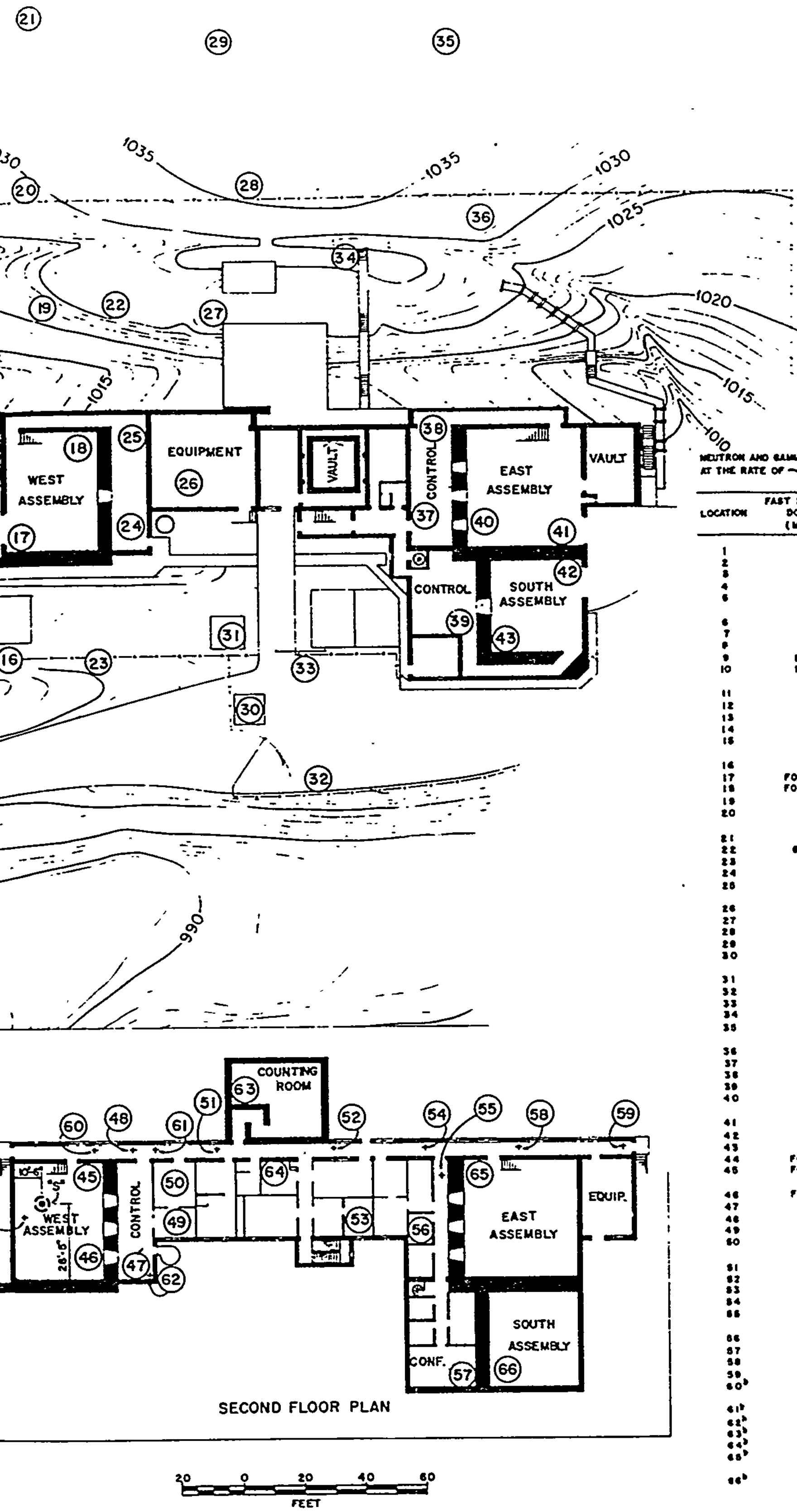

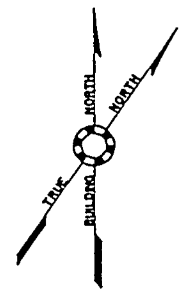

NEUTRON AND GAMMA-RAY DOSES AND INTENSITIES FROM 3.7×10^{16} FISSIONS PRODUCED AT THE RATE OF ~ 7×10^{12} FISSIONS/SEC IN A U^{235} SOLUTION - SOURCE AT "S", WEST ASSEMBLY -AREA

LOCATION	FAST NEUTRON DOSE[a] (MREM)	GAMMA-RAY DOSE (MREM)	FAST NEUTRON INTENSITY[a] (MREM/HR)	THERMAL NEUTRON INTENSITY (MREM/HR)	GAMMA-RAY INTENSITY (MREM/HR)
1	3	<20			
2	0	60			
3	16	85			
4		<20			20
5	24	125			
6	0	<20			
7	30	150			25
8	30	65	9		24
9	160	695			
10	135	650			40
11	16	105			35
12					150
13	15	<20			
14					20
15	72	345			
16	0	<20			
17	FOGGED	15250			
18	FOGGED	4575			
19	96	390			
20	42	150			
21	36	60			
22	690	715			
23	0	<20			
24		80			
25		110			
26	0	<20			
27	66	190	15		64
28	96	180			
29	114	60			
30	0	70	3		15
31	0	55			8
32	0	<20			
33	0	<20			
34	18	<20			
35	0	<20			
36	0	65			
37	0	<20			
38	0	<20			
39	0	<20			
40	0	20			
41	0	20			
42	0	<20			
43	0	<20			
44	FOGGED	>20000			
45	FOGGED	15400			
46	FOGGED	14300			
47	2	35	5	21	35
48			14	69	100
49	3	35	3	26	25
50			3	43	32
51	1	35	6	36	30
52			1	6	5
53	0	<20			
54			2	8	6
55	0	<20			
56	0	<20			
57	0	<20			
58	0	<20	2	6	5
59			2		4
60[b]	24	215			
61[b]			19		170
62[b]			5		60
63[b]			5		30
64[b]			5		20
65[b]		<20			
66[b]		<20			

a. ASSUMING AN RBE FACTOR OF TWO.
b. OBSERVATION MADE ON ROOF.

Radiation Field from Source in West Assembly Area.

Of greatest interest and value in this consideration of shield effectiveness are observations of the radiation dose incurred at a number of locations from a series of sharp, intense energy pulses produced in a superprompt critical assembly of unmoderated and unreflected ^{235}U-enriched uranium-molybdenum alloy. These data are a byproduct of a program of critical experiments supporting the design of the Oak Ridge Health Physics Research Reactor which was carried out in the Facility and was discussed earlier in this review. Gamma-ray sensitive film and, in some instances, neutron-sensitive film were exposed at a number of locations to a series of radiation pulses having an integrated yield of 1.7×10^{18} fissions. The exposures resulted from both prompt and delayed radiation. The data are given on the area plan in Fig. 20.

XII. NUCLEAR CRITICALITY INCIDENT EXPECTATIONS

The natural bases for evaluation of the risks associated with nuclear criticality incidents are the accumulated incident experience, albeit very limited, and the predictions from theoretical analyses. The course and effects of an incident can be expected to be somewhat as follows.

An incident, caused by the addition of reactivity to some accumulation of fissile material and initiated by ambient neutrons, consists of an initial interval of high instability when energy is released in one or more short, closely spaced pulses called "spikes." This initial interval is followed by a period of relatively constant energy emission at lower power, governed by some intrinsic quenching action, which is eventually terminated by a more complete shutdown device.

The magnitude of the energy release in an incident depends upon a number of factors. Among them are the properties of the experimental materials, the reactivity of the assembly at the onset of the incident, the magnitude and the rate of the reactivity addition which caused the incident, the strength of the ambient neutron field, and the effectiveness of the terminating device including its time response.

Consideration will be given to these factors as they relate to the expected consequences of a nuclear criticality incident at the Facility. As regards the last factor, a terminating device, it is unreasonable to expect

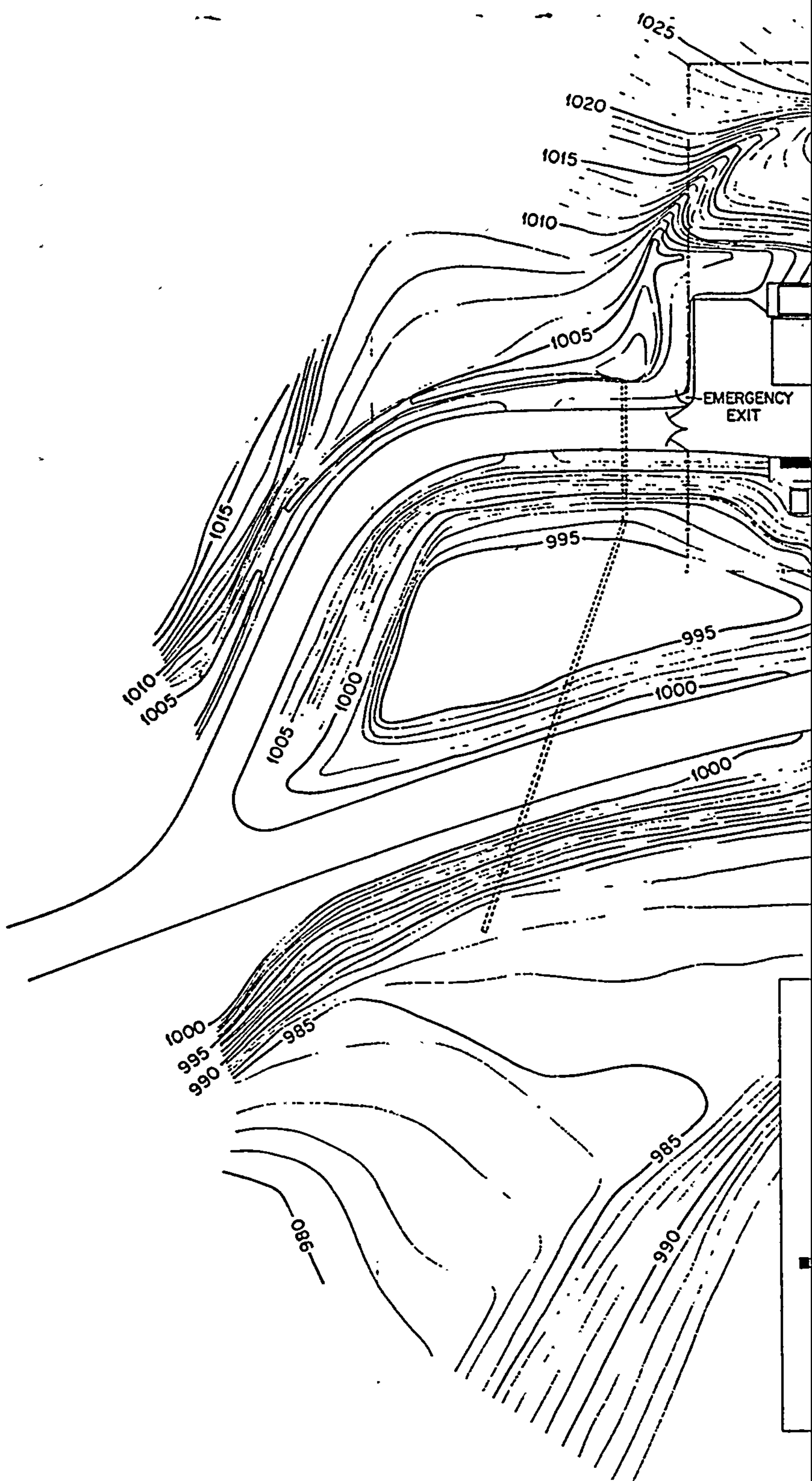
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Fig. 20. R

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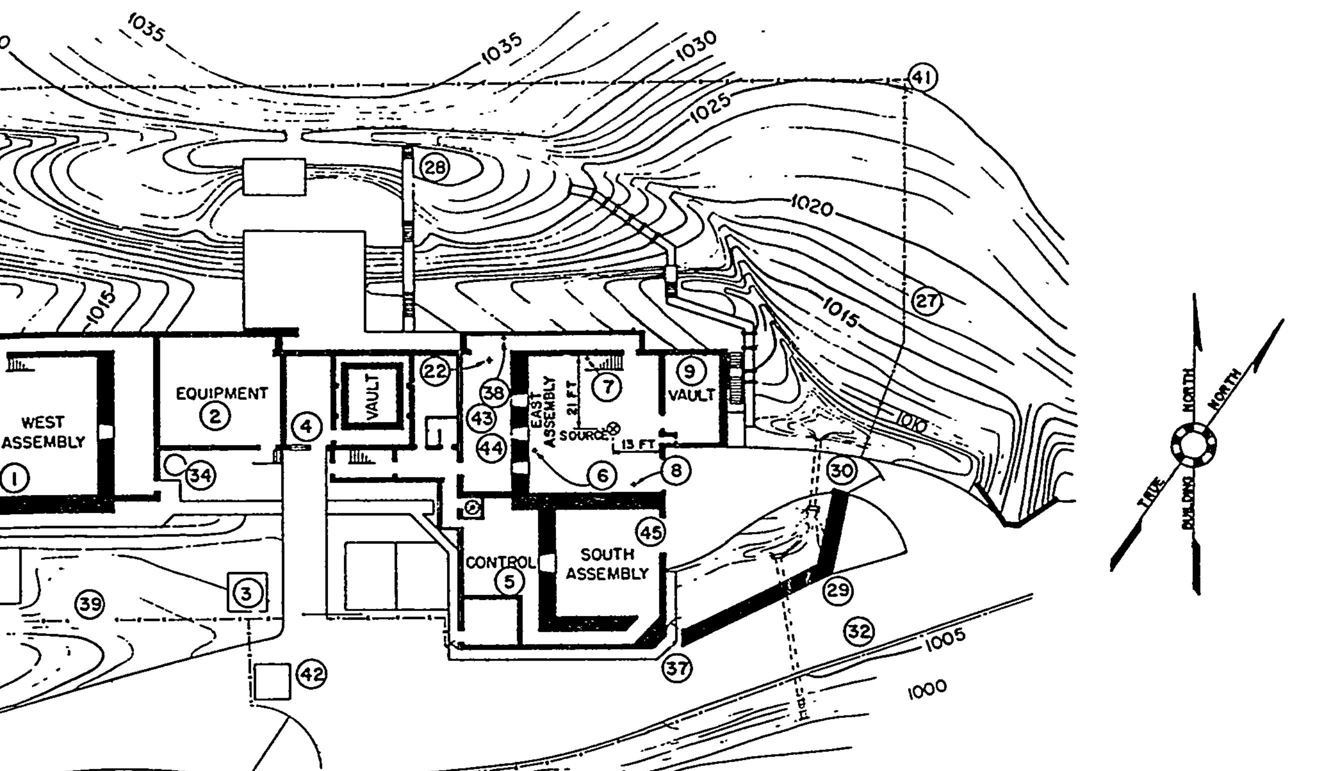

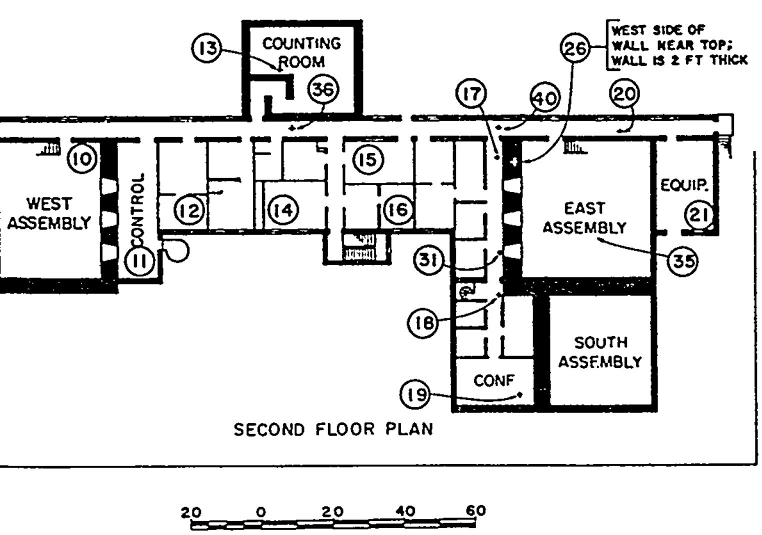

GAMMA-RAY DOSES ARISING FROM SUPERPROMPT-CRITICAL UNMODERATED U^{235} ASSEMBLY IN EAST ASSEMBLY AREA (~4 FT ABOVE FLOOR)

LOCATION	DOSE[a] (REM/10^{18} FISSIONS	LOCATION	DOSE[b] (REM/10^{18} FISSIONS
1	0.28	26	7.80
2	0.23	27	2.35
3	0.34	28	2.80
4	0.29	29	1.80
5	0.28	30	7.60
10	0.56	31	0.81
11	0.32	32	1.02
12	0.32	34	0.14
13	0.23	35	37.50
14	0.32	36	0.22
15	0.48	37	3.95
16	0.40	38	18.10
17	2.2	39	0.10
18	0.38	40	21.20
19	0.38	41	0.89
21	37.00	42	0.17
22	1.80	43	0.34
		44	0.71
		45	2.63

NOTES 1- AT LOCATIONS 6, 7, 8, 9 AND 20 THE EXPOSURE TO 1.7×10^{18} FISSIONS WAS GREATER THAN 100 REM.

2- THE ABOVE VALUES INCLUDE THE CONTRIBUTION TO THE DOSES BY THE DELAYED GAMMA RAYS EMITTED BY THE ASSEMBLY AFTER SHUTDOWN SINCE THE DETECTORS REMAINED IN POSITION THROUGHOUT THE TEST PERIOD. A DIRECT COMPARISON OF THE GAMMA-RAY AND NEUTRON DOSES DOES NOT REPRESENT, THEREFORE, A RATIO OF THE RELATIVE PROMPT GAMMA-RAY AND NEUTRON YIELDS BY THE ASSEMBLY.

a. FILM EXPOSED TO AN INTEGRATED YIELD OF 1.7×10^{18} FISSIONS IN 30 PULSES; NEUTRON SENSITIVE FILM EXPOSED AT THESE LOCATIONS SHOWED A MAXIMUM FAST NEUTRON EXPOSURE OF ~ 30 MREM.

b. FILM EXPOSED TO AN INTEGRATED YIELD OF 10^{18} FISSIONS IN 14 PULSES.

tion Field from Source in East Assembly Area.

complete failure of all normal and emergency shutdown mechanisms which are standard and necessary equipment on all critical assemblies. Such complete failure occurred in none of the recorded incidents in critical experiments facilities. There is no evidence that such complete failure would have occurred during any of the more than 15,000 experiments performed in this Facility.

For purposes of evaluation of the Facility, therefore, attention need only be given to the initial stages of unexpected occurrences. Assuming the availability of sufficient reactivity to initiate an incident, the rate of addition of the reactivity, the presence of reaction-initiating neutrons, and a source of negative reactivity produced by the incident remain to be discussed. The last of these is characteristic of the experimental material; the penultimate depends upon the material characteristics[f] and upon the administrative practice of providing a source of neutrons during the start-up of any experiment.

The course of an incident begins with the addition of reactivity, at some rate, to make the assembly of fissile material supercritical. Nothing further occurs until a persistent fission chain is started by a neutron from some source. At that time there is a rapid increase in power which is countered by negative reactivity introduced by some intrinsic property of the assembly. The principal property effective in introducing negative reactivity is the decrease in density of the fissile assembly resulting from the temperature increase producing, in turn, thermal expansion, vapor formation, boiling, or assembly-material dispersal. A concomitant phenomenon in liquids is the formation of bubbles of radiolytic gases. Another thermal effect is the change in neutron temperature.

A comprehensive record of all of the nuclear criticality incidents which have occurred both in critical experiments operations and in

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[f] A source of neutrons is inherent in the materials of which many assemblies are composed. For example, the spontaneous fission of ^{238}U and of ^{240}Pu, usually present as an impurity in ^{239}Pu, and the (α,n) reactions in some constituents provide an adequate neutron source for many assemblies.

processing fissile materials has been prepared by Stratton;[10] of those in critical experiments, the maximum energy release was that from 3×10^{18} fissions which occurred during a slow transient in a water moderated assembly of 2200 kg of slightly ^{235}U-enriched uranium in France.[g] The next greatest fission yeild was 3.8×10^{17}, and, in fact, in only six of the 17 incidents recorded was the yield 10^{17} or more. The incidents in the Facility have produced 1.6×10^{17} fissions or less.

Incidental reference is made to excursions which have occurred in process operations, all of which were with fissile material in solution. The pattern of those accidents was the same as that postulated above except as it was affected by the absence of a quickly acting mechanical shutdown device and the consequent dependence on other terminating means such as material changes. An example of this latter reactivity behavior is the incident in the Y-12 Plant at Oak Ridge reported by Callihan and Thomas[11] where a series of power spikes lasting about 3 min was followed by a 17-min, slowly decreasing low-power emission until an inflow of water diluted the solution to a subcritical concentration. It is estimated that the first of the series of spikes occurring in the initial 3-min period represented 10^{16} fissions, that the second spike occurred 15 sec later (after bubbles had disappeared), and that most of the fissions were produced within this 3-min interval.

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[g] The power is reported to have risen on a 0.25 sec period and the shutdown devices may have operated before prompt criticality was achieved. It is questionable whether this event should be classified as a critical experiment incident, although it is included for completeness. In any case, the high thermal capacity of the assembly and the shielding provided by the reflector certainly reduced the hazardous consequences of this occurrence below those of, for example, unmoderated, unreflected plutonium or highly enriched uranium.

10. W. R. Stratton, in "A Review of Criticality Accidents," Progress in Nuclear Energy, Series IV, Vol. 3, London, Pergamon Press, 1960; in Proceedings of the Karlsruhe Symposium on Criticality Control in Chemical and Metallurgical Plant, European Nuclear Energy Agency, 1961; also, "A Review of Criticality Accidents," USAEC Report LA-3611 (1967).

11. D. Callihan and J. T. Thomas, Health Physics 1, 363 (1959).

Of particular interest is the report[12] of a carefully scheduled and purposeful test in which reactivity was injected into a beryllium reflected uranium-zirconium-hydride core, SNAPTRAN-2. The total reactivity addition was 5.1 dollars in two steps. The first addition made the assembly 40 cents superdelayed critical and the second, one-half second later, introduced 4.7 dollars in 12 msec, a rate of 400 dollars/sec. It is significant that only 1.6×10^{18} fissions were produced even though the fissile material was constrained by the core vessel and by the beryllium reflector. The effective kinetic energy release corresponded to that from 0.4 lb of high explosive, or a utilization factor of about 2%. Some of this effect was due to the release of hydrogen. The integrated gamma-ray exposure at an unshielded point 30 ft distant over the first two hours including and following the excursion was 600 rem. These results illustrate the difficulty of achieving catastrophic releases of energy and radiation from even carefully planned excursions of uncommon severity.

One of the factors which strongly influence the yield in an incident is the presence of a neutron source. When a neutron source is not present there may be a delay between the formation of a superprompt critical assembly and the establishment of a persistent neutron chain resulting in the production of the first spike; this interval is called the "wait time." This effect has been observed only in unmoderated assemblies. Wimett _et al._[13] have reported intervals up to 11 sec, grouped around a peak at about 2 sec, between the assembly of a 5-cent superprompt critical mass and the pulse initiation. It is noted, however, that this interval decreases as the reactivity increment above prompt criticality increases because of the increased probability that a short fission chain will become a pulse-initiating chain. This higher probability reduces the risk associated with larger reactivity additions.

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12. "Quarterly Technical Report STEP Project, January 1966-March 1966," IDO-17186 (Nov. 1966).

13. T. F. Wimett _et al._, _Nucl. Sci. Eng._ _8_, 691 (1960).

Examples of assembly of solutions to prompt criticality in the absence of external neutron sources have occurred only in process operations with limited energy yield in the initial period comprising several spikes as discussed above.

The risk potential associated with operations in critical facilities can be established by examining the course and effects of an incident under the conditions typical of an experiment, i.e., normal procedures requiring the presence of a neutron source, functional shutdown devices, and controlled reactivity-addition rates.

In solutions of fissile material the initial interval, prior to action of the emergency shutdown device, may consist of several spikes each of short duration and each terminated by bubbles or other density effects. An analysis of the expected fission yield in this initial period has been reported by Hankins[14] who assumed that the only source of triggering neutrons was the (α,n) reaction with the oxygen of a uranyl nitrate solution. The strength of this source was experimentally determined as ~ 65 neutrons/sec in a critical volume of a solution of highly enriched uranium at the ^{235}U concentration (~ 50 g/L) requiring the least ^{235}U mass for criticality. Thus, for any other critical concentration the neutron source would be greater. The analysis showed the yield in an incident to be limited to 5×10^{16} fissions when reactivity was added at the rate of 10 cents/sec. Increasing the rate to 10 dollars/sec only increased the yield by a factor of 10. Increasing the source strength by a factor of 5 reduced the yield by 30%. These yields correlate reasonably well with those observed in incidents.

Since the above rates of reactivity addition to liquids grossly exceed those possible in the equipment described in Section V, it is concluded that the order of 10^{17} is the greatest yield to be expected from unscheduled incidents with enriched uranium solutions.

Of greater interest and importance is an examination of the effect of the additions of sufficient reactivity to make an assembly of an unmoderated,

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14. Dale E. Hankins, Nucl. Sci. Eng. 26, 110 (1966).

high-density fissile material supercritical. In incidents with solids the initial interval will usually consist of a single spike terminated by an overall temperature increase. The duration of the spike may be as short as a few tens of microseconds followed by an interval of a few hundred microseconds when the fission rate will be an order of magnitude less than the initial peak rate. This condition is then terminated by the normal shutdown device in the equipment.[4] The yield and the time behavior of the spike are, of course, dependent on the magnitude and rate of reactivity addition. A discussion of such incidents with and without a neutron source may be based on extensive analyses by Wimett et al.[13] and confirmed by experiments on the Godiva I and Godiva II assemblies. Consideration is given to three items: the energy yield as a function of the reactivity addition, the energy yield as a function of the time rate of reactivity addition, and the kinetic energy yield as a function of total energy yield. Although the study was made of the Godiva assemblies, the results can be applied with reasonable accuracy to any fast-neutron system whose dynamic characteristics are those of a solid or near-solid mass of metal. The conclusion of the study is that a most extraordinary rate of reactivity addition is required to produce catastrophic results.

[redacted]. The higher of these values corresponds to a fission density of 10^{15} per gram of fissile material. The graph of expected fission yield as a function of the instantaneous addition of reactivity above prompt criticality (Fig. 11 of Ref. 13) shows an addition of about 35 cents is required for this yield. Consideration of the above peak temperature, the mean temperature rise in the assembly, its negative temperature coefficient of reactivity (~ 0.3 cents/C^{o}) and the relative importance of neutrons in the region of peak temperature, the assembly reactivity will be reduced about 2.5 dollars by the temperature increase. The energy pulse in the assembly is thus shown to be self-terminating by reason of the temperature increase alone regardless of other effects.

It is doubtful, however, that this degree of supercriticality, 135 cents, can be achieved before a pulse will fully develop. It is probable that a pulse of smaller yield will occur, initiated prematurely by a stray neutron, within the time required for the reactivity insertion by any available practical means. In order to produce the full pulse, a studied effort must be made to minimize the presence of extraneous ambient neutrons and the reactivity addition must be made as nearly instantaneous as possible. A second graph (Fig. 12 of Ref. 13) records that 135 cents must be added to an assembly operating at a power of 0.01 watt[h] at the rate of 2500 dollars/sec to produce 10^{13} fissions/gram; that is, the insertion must occur in about 400 μsec. [It is remarked that the prompt neutron lifetime in an unmoderated, high-density assembly (~10^{-8} sec) makes necessary a reactivity insertion rate several orders of magnitude greater than that achieved in the SNAPTRAN-2 test in order to produce a comparable reactivity insertion before the pulse peaks.]

From a third graph (Fig. 13 of Ref. 13) it is observed that about 5% of the energy released in the above case will appear as kinetic energy. The energy released from 10^{18} fissions is equivalent to that from 14 lb of high explosive. The kinetic energy yield, however, is only that from 0.7 lb of explosive. (The damage observed from a Godiva incident was estimated equivalent to 0.024 lb of explosive whereas the total energy from the 1.2×10^{17} fission yield equals that from 1.7 lb, a utilization as kinetic energy of only 1.4%.)

It may be concluded, therefore, that 10^{18} fissions occurring in an unmoderated, high-density assembly cannot be achieved accidentally under the conditions of critical experiment operation.

In summary, analyses of the behavior of assemblies of fissile material subjected to unexpected increments of reactivity show that the resulting initial energy release is limited by the rate at which the increment can be added by means practicably available in the Facility. Dependable equipment terminates the excursion within the order of a hundred milliseconds thereby prohibiting continuing energy release. It is recognized that no electromechanical shutdown device will respond sufficiently quickly to

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[h]The neutron population at this steady state power is roughly that produced by the Pu-Be (or Po-Be) source usually present at the start of an experiment.

prevent unequivocally the occurrence of accidental criticality. Even in the event of the highly improbable failure of this shutdown device it has been shown that the energy initially released in a nuclear criticality incident will, through some temperature-density effect, make the assembly subcritical.

If the assembly is liquid, prompt criticality may be again achieved within a short time, only to be countered as before. This cycle will repeat until, within a few minutes, heat sources and heat losses will equalize and energy will be produced at a constant rate until some material change makes the volume subcritical.

In the case of an unmoderated, high-density assembly, the energy in the initial spike will increase the temperature sufficiently to make the assembly subcritical. There it will remain until cooling is sufficient to return to delayed criticality. This cooling will require the order of an hour, adequate for putting other methods of reactivity reduction into effect.

In any case, adequate time is available for evacuation of an affected area before the excursion has progressed much beyond the initial stage. Tested emergency procedures have demonstrated that personnel can evacuate the building in less than one minute.

For these reasons, therefore, 10^{18} fissions are specified as the maximum energy release from a nuclear excursion of importance to the evaluation of the safety of the Facility. This yield is an order of magnitude greater than believed credible. This discussion of risk has been directed toward critical assemblies having a mass of the order of 100 kg and an expectation of a fission yield per event of 10^{17} to 10^{18}. An analysis of an assembly with mass an order of magnitude or so greater shows that the external effects of excursions correspondingly larger would be no greater because of the increased thermal capacity and the self-shielding capabilities of the larger units. Super Kukla is such an assembly; it consists of 4500 kg of enriched uranium-molybdenum alloy and routinely generates 3×10^{18} fissions per pulse.[15]

Consideration of assemblies containing an array of individually subcritical units in which the total mass is $\sim 10^3$ kg of uranium, for which the

15. F. Kloverstrom, Lawrence Radiation Laboratory, Livermore, personal communication (1967).

structural integrity is assured and the scram mechanisms are functional, shows that the resulting consequences of step insertions of reactivity comparable to the above cases would be less than 10^{18} fissions. Experimental verification of an increase in neutron lifetime and a decreasing sensitivity of the array to reactivity changes as the assembly size increases confirms these as principal reasons for this behavior.[i]

XIII. CRITICALITY AND RADIATION INCIDENT CONSEQUENCES

Airborne Contamination Evaluation.

Reference to the data from radiation surveys summarized in Figs. 18, 19, and 20 shows that the maximum direct personnel exposure to be expected in normally occupied areas to radiation arising from the assumed 10^{18}-fission incident is 1 rem. This exposure is to be compared with the radiation protection standard specified by AEC Manual Chapter 0524 for occupants of controlled areas as 3 rem per quarter year.

Established procedures for evacuation of personnel from the Facility building and from the Facility area if necessary provide adequate protection against radiation exposure from airborne fission products and from fissile-material contamination. The area evacuation route would be guided by information from the local anemograph.

The Laboratory and the Facility also have responsibility for protecting the public from undue exposure. The point of nearest public access to the Facility is on a highway, known as Bethel Valley Road, shown on Fig. 1 to be 4200 ft distant.

The dilution of airborne contamination carried over this distance may be obtained by one of Sutton's[16] diffusion equations. It has been recommended by Gifford[17] and by Burnett[18] that an appropriate form of the relation is

$$\frac{X}{Q} = \frac{2}{\pi u C^2 d^{2-n}} , \qquad (1)$$

where X/Q, the dilution factor, is the concentration at the point of exposure expressed in curie-sec/m^3 per curie released at the source, u is

[i] See, for instance, O. C. Kolar *et al.*, "Interaction in Arrays of Fissile Materials," UCRL-14245 (1965).

16. "Meteorology and Atomic Energy," U.S. Dept. of Commerce, Weather Bureau, Chapter 4, "An Outline of Atmospheric Diffusion Theories," (July 1955).
17. F. A. Gifford, U.S. Weather Bureau, Oak Ridge, Tenn., personal communication (1961).
18. T. J. H. Burnett, ORNL Health Physics Div., personal communication (1966).

the average wind speed in m/sec, d is the distance from the source to the exposure point in meters, and C and n are constants whose values depend upon local conditions. Typical values suggested[17] for this locale are: $n = 0.25$, $C = 0.1\ (m)^{n/2}$ and $u = 2.5$ m/sec.

The risks to personnel arising from fission product dispersal are an external dose due to the radioactive cloud and an internal dose resulting from inhalation of activity. The external dose, in rem, is given by Burnett[19,20] to be

$$Z = 0.26 \frac{X}{Q} ES, \tag{2}$$

where E is the effective energy of the radioactive material, assumed to be 1.5 MeV/disintegration, and S is the activity release in curies. The internal dose, in rem, to a body organ is given by

$$D = 73.8\ fI \sum E(RBE)N\ T/m, \tag{3}$$

where I = inhaled activity, μc,
- f = fraction of inhaled activity retained in a body organ,
- T = effective half life of the retained fraction, days,
- m = mass of organ, g,
- E = energy absorbed by organ, MeV,
- (RBE)N = product of relative biological effectiveness and local disposition factor.

The fission products most readily released from melted fissile material are iodine and the noble gases. It has been shown that the internal exposure resulting from inhalation of iodine is more severe than all other exposures, both internal and external, even if all the fission products were released.[19,20] Using Eq. 3, Burnett[20] has determined the internal dose to a thyroid with a mass of 20 g to be 1.5 rem per μc of inhaled ^{131}I, where $T = 7.6$ days, $f = 0.23$, and $\sum E(RBE)N = 0.23$ MeV. The total internal dose then would be

$$D_I = 1.5 \frac{X}{Q} BS, \tag{4}$$

19. T. J. H. Burnett, Nucl. Sci. Eng. 2, 382 (1957).
20. T. J. H. Burnett, in an Appendix to a report by M. I. Lundin, "Health Physics Research Reactor Hazards Summary Report," ORNL-3248 (1962).

where B is the breathing rate, assumed to be 5×10^{-4} m^3/sec, and X/Q and S are as defined previously.

On the basis of the above, estimates can be made of the external and internal doses resulting from an accident at the Facility producing 10^{18} fissions. Each assembly area has an air capacity of about 3×10^4 ft^3 and is normally continuously exhausted by an ~ 1000 cfm fan. If the shutdown devices fail to deactivate this fan, a minimum of 30 min will be required to discharge the airborne fission products to the outside of the building.

For the external exposure it is assumed that 10% of all the products generated in 10^{18} fissions are released to the assembly area atmosphere and that they, on the average, decay for 15 min before discharge from the building. These conditions establish a release of 1.2×10^3 curies and would give, from Eq. 2, the following external doses at several distances.

Distance (meters)	External Dose (rem)
300	0.50
500	0.19
1000	0.05
1500	0.02

For evaluation of the internal exposures, it is assumed, as a very conservative estimate, that all of the iodine isotopes, expressed in an equivalent quantity of ^{131}I, are discharged from the building. This amount is ~ 5.5 curies produced in 10^{18} fissions and will increase to ~ 6 curies during the first hour owing to the decay of tellurium; the inclusion of tellurium decay adds further conservatism to the estimates. The resulting internal doses at various distances, obtained from Eq. 4, are:

Distance (meters)	Internal Dose (rem)
300	5.2
500	2.2
1000	0.6
1500	0.3

These results are to be compared to the values, specified in Federal Regulation 10 CFR 100 for the location of nuclear reactors, whereby, for guidance in protection of the public against accidental radiation exposure, yearly doses of 25 rem whole body and 300 rem thyroid are assumed permissive in a single exposure. It is seen that the estimated exposures 1500 m (~ 4500 ft) distant from the source are less than the permissive ones by about a factor of 1000.

It should be pointed out at this time that, as shown in Fig. 1, the Facility is almost surrounded by 200-ft high, partly wooded hills. This location provides moderate shelter from winds aloft and requires that local air disturbances drift down a winding valley toward the 4200-ft-distant, by air line, highway with considerable opportunity for impingement on wooded slopes. It is emphasized, therefore, that significant additional factors of safety are included in the above exposure estimates through omission from the calculations of losses by fallout and by foliar deposition and of the highly probable motion of personnel on the highway. The true potential exposures become a complex problem in travel patterns, contamination cloud dimensions and speeds, and distances from the Facility complicated by topography and by attrition through deposition.

A second potential risk to the public arises from airborne fissile material released as a consequence of an incident at the Facility. Estimates have been made by Burnett[21] of the permissible masses of ^{235}U, ^{233}U, and ^{239}Pu, released at the Facility, which would result in not excessive exposures to the public. The bases for these estimations are, first, the consequences of a short term exposure to inhaled contamination are no worse than those of an extended exposure provided the product of the exposure time and the concentration of the contaminant in the air are equal in the two instances. The second basis is the consideration that the accidental dose may be equal to a one-year occupational dose. The conditions of air transport assumed in this case of fissile particulates are the same as those in the considerations of fission product transport, including neglect of fallout and attrition by deposition. The resulting

21. T. J. H. Burnett, ORNL Health Physics, personal communication (1966). We are particularly grateful to Mr. Burnett for this analysis.

calculated permissible masses released at the Facility are:

^{239}Pu	5.8 g as a soluble salt
^{239}Pu	58 g as an insoluble material
^{233}U	1000 g
^{234}U-^{235}U	85 kg[j] .

Having established some measure of the permissible fissile material release at the Facility, it now becomes necessary to postulate a means whereby those quantities could be released with reasonable probability. Entire utilization of the energy developed in 10^{18} fissions will melt and vaporize 13 kg of fissile metal; it will boil and vaporize about the same mass of solution. These are extreme quantities because all heat losses are neglected. On the basis of studies at ORNL,[22] the estimate that 10% of solids vaporized within an assembly area will find their way outside, applied previously to fission product liberation (except iodine), is considered to be very conservative when applied to fissile material. Nevertheless, it does predict that the order of one kilogram of an element will be liberated from an assembly area and become available for dispersal.

It is apparent, therefore, from comparison with Burnett's values, that the public will not be subjected to undue exposure to uranium used in the Facility. Before inauguration of experiments with plutonium further and more complete analyses must show that the above estimates are conservative by a factor of ten or that additional containment must be provided.

Other Criticality and Radiation Incidents

The preceding considerations of the consequences of incidents to persons within or near the Facility assumed their presence in areas designated for occupancy during the performance of critical experiments, a condition enforced by strict administrative practices. If there were a

[j] This limit is imposed by chemical toxicity; the value for radiation exposure is 4000 kg.

22. G. W. Keilholtz, Nuclear Safety Information Center, ORNL, personal communication (1966).

supercritical assembly and a simultaneous violation of these practices, the consequences to personnel could be severe, as evidenced by the first two critical experiment accidents at the Los Alamos Scientific Laboratory which were fatal to two employees even though the yields[23] were only 10^{16} and 3×10^{15} fissions. Some of the survivors of these incidents were within a few feet of the source.

The nuclear accident of most serious consequence is, therefore, the one which could happen during preparations for critical experiments. It could, for example, occur in the transport or storage of the fissile materials. These operations, like those in production operations, are governed by strongly enforced acceptable administrative practices. The initial stages in the assembly of a critical experiment, of necessity often done manually, are monitored by personnel radiation detectors.

Certain naturally radioactive materials and generators of other nuclear reactions are used within the Facility and present potential hazards. Included in this category at the present time are plutonium in radiation detecting devices, plutonium and polonium in neutron sources, radium as a source of gamma rays, the decay products of ^{232}U (a contaminant in ^{233}U) which are gamma-ray emitters, ^{234}U (an impurity in ^{235}U) which is a relatively strong alpha-particle emitter, and fast neutrons arising from high-energy particles impinging on an appropriate target material.

The plutonium foils used as neutron detectors are contained in an ORNL approved manner. The only conceivable hazard is the contamination which might result from dispersal of the plutonium as a result of fire.

The plutonium and polonium used in neutron sources are encapsulated with beryllium. The plutonium sources are used as received from the vendor and are doubly enclosed in welded containers, the inner one of tantalum and the outer of stainless steel. A study by Kaufman[24] of the containment

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23. J. G. Hoffman, "Radiation Doses in the Pajarito Accident of May 21, 1946," LA-687 (May 26, 1948).

24. J. L. Kaufman, "Hazards Summary and Safety Procedures for Reactor Controls Plutonium-Beryllium Neutron Source," ORNL-CF-60-6-20 (June 8, 1960).

capabilities of this construction indicates its adequacy. Although the Po-Be neutron sources are welded in stainless steel by the vendor, it has been the practice to further enclose them in either brass or stainless steel outer containers. In addition to the extra protection, this practice allows facility in methods of attachment to equipment and to handling tools. The radium sources are sealed in small needle-like cylinders which, in turn, are enclosed in metal cylinders. It is necessary, of course, to provide adequate shielding to avoid exposure to the radiation emitted from these sources.

Although the risks associated with the rupture of any one of the above containers and the attendant inconvenience and cost of the necessary decontamination have, in the experience of this Facility, far exceeded those incurred in the accidental prompt critical incidents, it is believed that regular and frequent tests for leaks (approximately semiannual) minimize the possibility of severe contamination.

The uranium isotopes, used as experimental materials, are potential sources of personnel and area contamination because of their alpha-particle activity and their gamma-ray emitting characteristics.

These contamination potentialities are best countered by good housekeeping, by frequent radiation surveys, and by adherence to shielding requirements for gamma-ray protection.

Some experiments require an intense source of fast neutrons produced in nuclear reactions arising when high-energy deuterons impinge upon tritium or upon deuterium. Associated personnel risks are exposure to the neutrons and contact with the high electrical potential necessary for the acceleration of the particles. Operators are routinely protected against the former by the shielding provided in the Facility construction since the neutrons are usually produced in one of the assembly areas and their control is from a shielded control room. Against electrical shock and inadvertent exposure during setup or during adjustment there is strict self-disciplined control by the experimenters supplemented, in the latter case, by neutron monitors. The tritium itself must be recognized as a potential contaminant.

XIV. MISCELLANY

Fire

Although the building is almost entirely of fire resistant construction, there is finite possibility of the ignition of some structural component or of uranium metal. The major consequence of a uranium-metal fire will be, of course, a dispersal of alpha-particle contamination. Sensitive areas are equipped with extinguishers recommended by knowledgeable authorities for combating metal fires. In case of failure of immediate control, an affected area would be abandoned, the ventilation system deactivated and reentry made with suitable protective equipment. Areas in the building where fissile materials are neither used nor stored are to be sprinklered.

Seismology

The infrequency and low intensity of seismological distrubances in the area under discussion have been reviewed and documented in earlier reports of this kind.[25] It is impossible to certify that every disorder of a storage or experimental assembly of fissile material would decrease its reactivity. Reasonable recognition is made of the adverse possibility in the design of storage facilities and experimental equipment.

Meteorology

In the opinion of the local office of the U. S. Weather Bureau, the meteorology immediate to the Facility is too complex for meaningful generalization.[26] In the absence of an inventory of long-lived fission products in this remotely located Facility, simple and pessimistic considerations of the extent of wind borne radioactive contamination show that the problem is insignificant.

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25. See, for example, F. T. Binford *et al.*, "The High Flux Isotope Reactor," ORNL-3572, Vol. 1, (May 1964).

26. F. A. Gifford, U.S. Weather Bureau, Oak Ridge, Tenn., personal communication (1962).

APPENDIX

EMERGENCY PROCEDURES OAK RIDGE CRITICAL EXPERIMENTS FACILITY

I. POLICY

The policy of the administration of Building 9213 is to establish appropriate procedures for the protection of personnel in the event of a critical accident in those areas of the building normally containing potentially chain reacting quantities of fissile materials. These procedures are coordinated with those of the Y-12 Plant.

II. GENERAL INFORMATION

A. Purpose

These procedures prescribe the actions of persons in and near the building at the time of a critical accident. The occurrence of such an accident is signalled by an alarm described in Section II.B. An emergency elsewhere affecting Building 9213 personnel or an emergency within the building not due to a critical accident will be announced over the public address system. Appropriate instructions will be announced also.

B. Alarm

An audible alarm (bells, horns and sirens sounding simultaneously) signals the occurrence of a critical incident in Building 9213. This alarm is actuated by radiation monitors located, in groups of three, in each of five sensitive areas within the building. The alarm is sounded when the radiation at two of the three monitors constituting a group reaches a preset value. The monitors are located on the east wall of the East Assembly Area (Room 108), on the west wall of the South Assembly Area (Room 113), on the south wall of the central vault (Room 105), on the north wall of the solution storage area (Room 102), and on the east wall of the West Assembly Area, upper level (Room 201).

The location of the monitors initiating the alarm will be identified as a room number by the illumination of the appropriate block on each of five annunciator panels. These panels are in the east control room (Room 107), in the south control room (Room 112), in the shop (Room 104), in the west control room (Room 202), and at the intersection of the corridors on the second floor of the building. The locations of the monitors and of the panels are shown on Figs. A1 and A2.

The initiation of an alarm stops all air-moving equipment in the building, turns on the flashing red light at the intersection of South Patrol Road and South Fourth Street (warning traffic not to proceed into South Fourth Street), and indicates in the office of the Y-12 Plant Shift Superintendent. This radiation detector system is tested each month.

C. <u>Evacuation Routes and Assembly Points</u>

Building evacuation routes and the two assembly points to which they lead are shown on Figs. A1 and A2. The primary assembly point is on the north side of the building behind Room 215; the secondary assembly point is west of the building on the road to Bethel Valley sufficiently distant not to be visible from the building.

D. <u>Location of Portable Emergency Equipment</u>

1. Primary Assembly Point

A power megaphone, a Bell telephone, and two γ-survey meters (maximum range 50 r/hr) are located at the primary assembly point.

2. Guard Post No. 3

A γ-survey meter is located in Y-12 Guard Post 3 at the South Portal. The guard on duty has been instructed to take it to the secondary assembly point.

3. Secondary Assembly Point

An extension of the Bell telephone at the primary assembly point is located at the secondary assembly point.

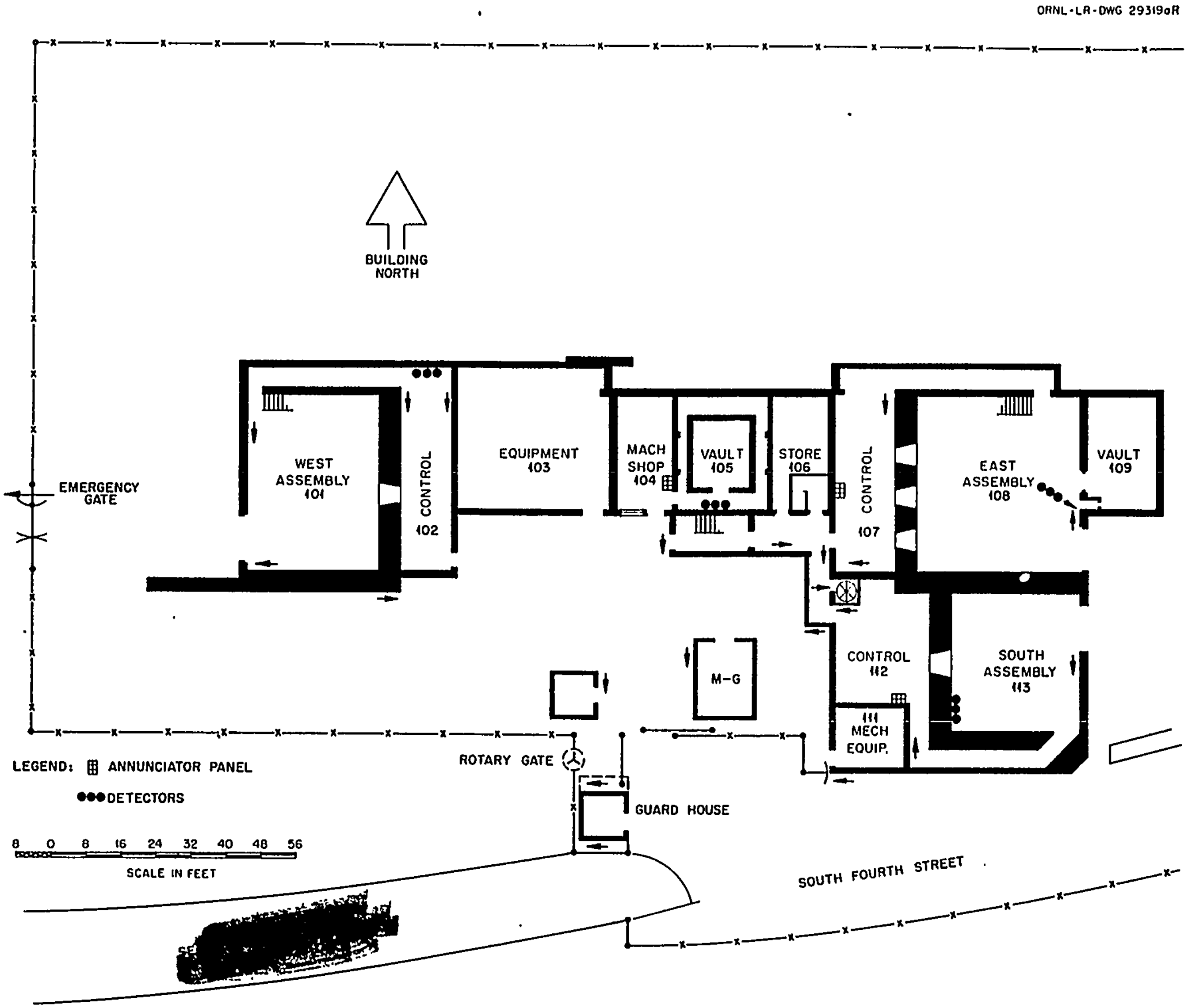

Fig. A1. Ground Floor Evacuation Route, Critical Experiments Facility ORNL, Y-12 Plant.

ORNL-LR-DWG 29319bR

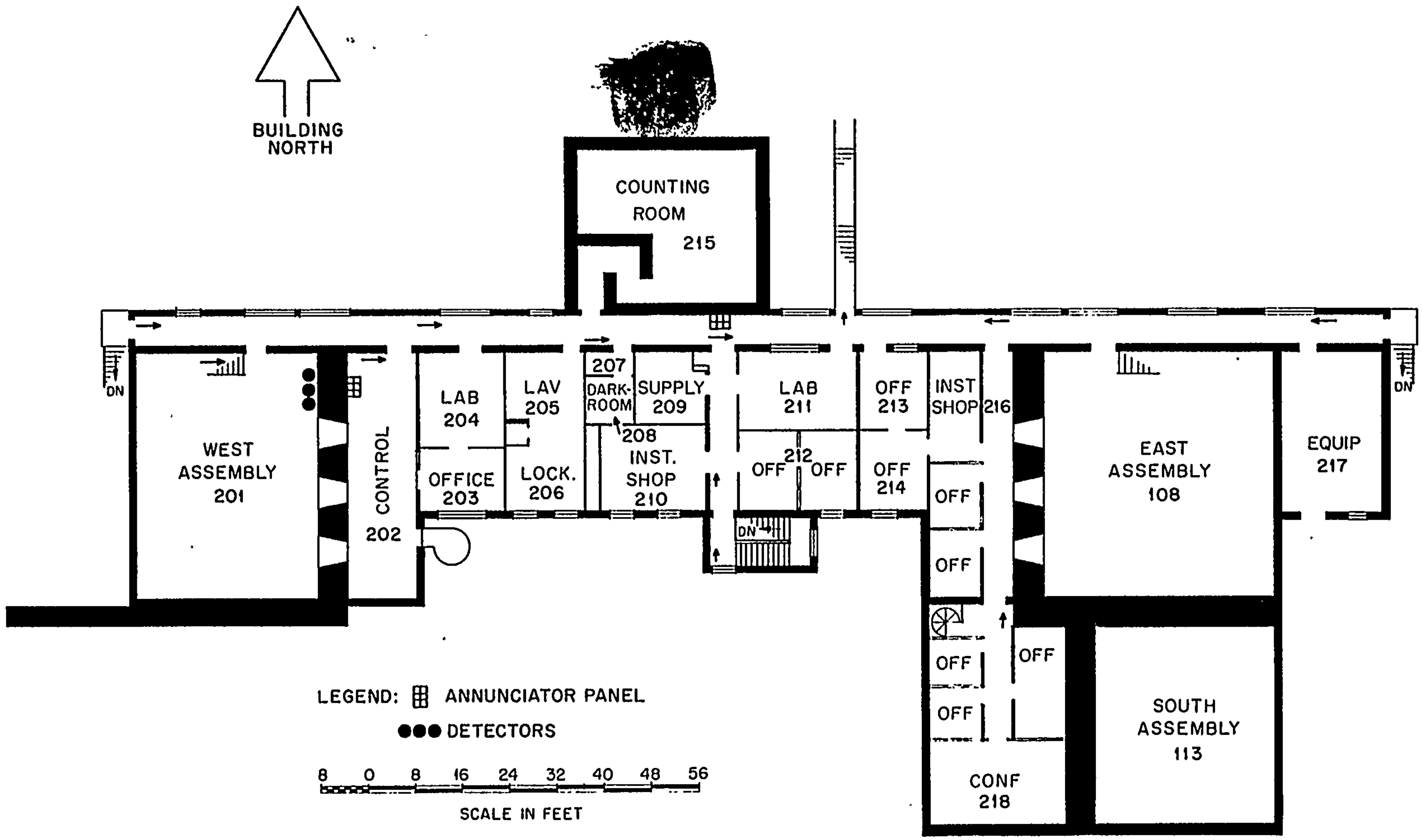

Fig. A2. Second Floor Evacuation Route, Critical Experiments Facility ORNL, Y-12 Plant.

4. Other

Miscellaneous radiation detectors are located within the building.

III. PROCEDURES

A. Immediate Action

At the sound of the alarm all persons shall immediately evacuate the building along indicated and marked routes to the assembly points. However, persons directly responsible for critical experiments and other operations with fissile materials not involved in the accident shall leave all equipment shut down and all materials in a critically safe condition prior to evacuation. Prescribed routes may be violated by knowledgeable individuals with direct information on the location, cause, and intensity of the critical accident.

Members of the building staff shall be responsible for escorting all visitors. The Post 3 (South Portal) Security Guard has been instructed to open the vehicular gate and proceed to the secondary assembly point taking the radiation survey meter. Telephones will provide common communication between the assembly points and the Y-12 Plant Shift Superintendent's office. The building staff shall take conveniently available radiation detectors to the assembly points. The Local Emergency Director (LED) or his representative shall establish that all persons known to thave been in the area at the time of the accident have reached an assembly point.

B. Subsequent Action

The LED, or his representative, shall measure the radiation field at each assembly point. If the field is found to be in excess of 100 mr/hr, personnel shall be relocated. The relocation site will be established upon information from personnel interrogation and by radiation surveys.

The Health Physicist, or his representative, shall read personnel dosimeters immediately. The Health Physicist shall be responsible for surveying, with a portable radiation detector, the film badge of each person in or near Building 9213 at the time of the alarm. When the occurrence of a criticality incident has been established, the Health Physicist shall be responsible for collecting the film badges of these persons.

Necessary evacuation of personnel shall be to X-10 or to Y-12 along a route appropriate to the local radiation environment. Any transportation and security clearance shall be requested from the Y-12 Plant Shift Superintendent by the LED.

Should the radiation at the assembly point be found not excessive, the occurrence of a critical incident and its location shall be established by personnel interrogation and by extended radiation surveys by members of the Emergency Squad. Subsequent action, including reentry of the building shall be taken only after investigation has shown the unlikelihood of recurrence of the incident and after radiation surveys show the actions to be permissible.

Should it be established by personnel interrogation and by radiation surveys that no critical incident has occurred, personnel shall be directed by the LED or his representative to return to work.

To the fullest extent practical, the Y-12 Plant Emergency Director and the ORNL Applied Health Physics Group will be kept informed of radiation conditions associated with any monitor-system alarm.

C. Actions During Unoccupancy

Each member of the Building Staff shall respond promptly to requests from the Y-12 Plant Emergency Director for information, advice, or assistance relevant to alarms occurring during periods when the building is not occupied by a member of its staff.

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